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A MULTIVARIATE AUTOREGRESSIVE FORECAST MODEL FOR SHORT-TERM PREDICTIONS

APRIL 1981

By

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Under Contract DAAG29-72-D-0100

Contract Monitor: Bruce T. Miers

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Data from 3 years (1972-1974) of synoptic observations collected at seven German stations were used to determine multivariate autoregressive (MVAR) models to make short-term forecasts (3 to 12 hours) for six atmospheric variables (temperature, u-wind, v-wind, visibility, ceiling height, and height of first cloud layer). So that certain tactical constraints could be met, the order and number of predictor variables used by the MVAR models were limited. To emphasize the variance of low ceiling and visibility situations, a variable transformation was

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20. ABSTRACT (cont)

performed upon the observations of visibility and the cloud height variables. The best forecasts were obtained when six seven-parameter MVAR models were used. Each model produces a forecast for a particular variable, using the observations at the seven stations as parameters. The variables that can be forecast best are temperature and the u- and v-components of the wind with about 95, 75, and 60 percent of the variance, respectively, explained by the model. From 45 to 70 percent of the variance is explained by the model for visibility while from 30 to 60 percent is explained for the cloud height variables. Finally, data from observations collected in 1976 were used in testing the MVAR models, and the error statistics from these actual forecasts agreed with theory.

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Section

1. Introduction

The purpose of this research is to develop a multivariate autoregressive (MVAR) climatological model to be used for short-term forecasting (3-12 hours) of various atmospheric variables over a limited area in a tactical situation. The atmospheric variables to be forecast are temperature, visibility, ceiling height, height of the first cloud layer, and the u- and v-components of the wind. The tactical situation facing the forecaster is this: all of his communications are cut off and he must, using only a small computer with limited storage area, make 3-hourly forecasts of the aforementioned variables out to 12 hours over an area on the order of 100 km square. Using an MVAR model the forecaster can not only make the necessary forecasts, but confidence intervals about the forecast values can also be computed to aid in any decision-making processes based on these forecasts.

In the next section a theoretical description of an MVAR forecast model is presented. In such a model the forecast value of a variable (predictand) is assumed to be a function of present and past observations of that variable as well as other predictor variables. The relationships between the predictand and the predictors are carried within the coefficient matrices of the model which are determined from the past history of observations. Embedded within these coefficient matrices will be the effects of complex terrain upon the inter-relationships among the predictand and predictors.

The data used in this study consisted of five years of 3-hourly observations of the six variables to be predicted as well as one predictor variable, the dewpoint temperature, for the following north German stations: Hannover, Bremen, Braunschweig, Boizenburg, Magdeburg, Weissen, and Wernigerode. In Section 3 the preliminary data analysis is described in which the distribution and various statistical properties of the variables were determined. From the results of this analysis it was decided that the cloud height ... ibility variables be transformed in such a way that the variance pre... during low visibility and ceiling conditions be emphasized so that ... conditions could be better forecast.

Finally, in Section 4 various MVAR forecast models were determined using the first three years of data (1972-1974). With ... to the limited data storage available to the forecaster it was ... the final models could only utilize values of the predictors for the period preceding the forecast time. It was found that under the ... constraints the best forecasts could be obtained using six 7-parameter MVAR models. Each model produces a forecast for a particular variable ... the observations at the seven stations as parameters. The variables ... one can theoretically expect to forecast best are temperature and the ... and v-components of the wind with about 95, 75 and 60 percent of the variance, respectively, explained by the model. The percent variance one ... expect to explain ranges from about 45 to 70 for visibility and from about 30 to 60 for the cloud height variables. Using the data from 1976 the MVAR models were tested and the error statistics from these actual forecasts were found to agree quite well with theory.

2. Multivariate Autoregressive Forecast Model

In this section the theory behind a multivariate autoregressive (MVAR) forecast model will be outlined. Suppose that one has collected m time series consisting of n observations each for m different variables. Further assume that the value of the sample mean has been subtracted from each of these observations. Using these observations one would like to develop a forecast model such that future values for $m_1 \leq m$ of these variables may be predicted, given the present and a certain number of past values of these variables. For a particular time i the observations for the m variables are denoted by the m-dimensional column vector, X_i, where the first m_1 elements of X_i belong to the m_1 time series to be predicted while the last $m - m_1$ belong to those series to be used to aid in the forecast. The p-th order MVAR model is:

$$X_i + A_1 X_{i-1} + \ldots + A_p X_{i-p} = Z_i \tag{1}$$

where the A's are $m \times m$ coefficient matrices and Z_i is an m-dimensional white noise column vector. Such a model would use the present observations (X_{i-1}) and p-1 past observations in order to predict the values of the variables one interval in the future (X_i). The variance of the white noise process (Z_i) represents the one-step prediction error variance of forecasts made with this model. Two things must be determined, using the collection of n observation vectors, before an MVAR forecast model can be developed. First, the proper order model must be selected and then the coefficient matrices for that order model must be computed.

The procedure outlined in this section is the multivariate generalization given by Whittle (1963) of the recursive method developed by Durbin (1960) for the fitting of univariate autoregressive models of successively increasing order. Except for the inclusion of the Akaike FPE criterion (Akaike, 1971), it is identical to that presented by Jones (1964). The Akaike FPE parameter is an estimator of the one-step prediction error of the MVAR process. The use of the FPE criterion permits one to find the order model with the smallest one-step prediction error. The analysis procedure can be described simply: first, L + 1 MVAR models whose order successively increase from zero to L are fitted to the n m-dimensional observation vectors using the recursive method to be detailed below; for each order model a value of the Akaike FPE parameter is computed, and finally, an MVAR model whose order is that for which the minimum FPE was found is fitted to the data using the same recursive method. This is the model that one would use for prediction.

The first step in the analysis method is the calculation of the lag sums

$$G_p = \sum_{i=p+1}^{n} X_i X'_{i-p}, \; p=0,1,2,\ldots,L,$$

$$G_{-p} = G'_p$$

where G'_p denotes the transpose of the m x m matrix G_p. In the following equations the p-th order residual matrices for the forward and backward autoregressions are denoted by S_p and $\overline{S}_p$, respectively. The k-th coefficient matrices for the p-th order forward and backward autoregressions are denoted by A_k^p and $\overline{A}_k^p$, respectively. The determinant of the $m_1 \times m_1$ submatrix in the upper left-hand corner of S_p is denoted by $|S_p, m_1|$.

Initialization: $S_o = \overline{S}_o = G_o$

$$A_1^1 = -G_1 \overline{S}_o^{-1}$$

$$\overline{A}_1^1 = -G_{-1} S_o^{-1}$$

$$FPE_o = \left(\frac{n+1}{n-1}\right)^{m_1} |S_{o,m_1}| .$$

For p = 1,2, ..., L-1,

$$S_p = G_o + A_1^p G_{-1} + \ldots + A_p^p G_{-p}$$

$$\overline{S}_p = G_o + \overline{A}_1^p G_1 + \ldots + \overline{A}_p^p G_p$$

$$FPE_p = \left(\frac{n+pm+1}{n-pm-1}\right)^{m_1} |S_{p,m_1}|$$

$$A_{p+1}^{p+1} = -(G_{p+1} + A_1^p G_p + \ldots + A_p^p G_1) \overline{S}_p^{-1}$$

$$\overline{A}_{p+1}^{p+1} = -(G_{-p-1} + \overline{A}_1^p G_{-p} + \ldots + \overline{A}_p^p G_{-1}) S_p^{-1}$$

$$\left.\begin{aligned} A_k^{p+1} &= A_k^p + A_{p+1}^{p+1} \overline{A}_{p+1-k}^p \\ \overline{A}_k^{p+1} &= \overline{A}_k^p + \overline{A}_{p+1}^{p+1} A_{p+1-k}^p \end{aligned}\right\} \qquad k = 1,2, \ldots, p.$$

Finally,

$$S_L = G_o + A_1^L G_{-1} + \ldots + A_L^L G_{-L}$$
$$FPE_L = \left(\frac{n+Lm+1}{n-Lm-1}\right)^{m_1} |S_{L,m_1}|.$$

Thus, if one had found that FPE_k had been a minimum and had fitted at k-th order MVAR model to the data, the prediction for X_i given $X_{i-1}, \ldots, X_{i-k}$ would be

$$X_i = -A_1^k X_{i-1} - A_2^k X_{i-2} - \ldots - A_k^k X_{i-k} \qquad (2)$$

At this point the values of the sample means for the variables to be predicted would be added back to the X_i vector to give the final prediction value for each variable.

Finally, one can determine the quality of the predictions from such a model by computing the prediction error covariance matrices. For a k-th order model the one-step prediction error covariance matrix is

$$V_k^1 = \frac{1}{n-mk} S_k \ .$$

Successive predictions can be made using (2) by merely replacing observed values by predictions as one steps further into the future. The following recursion is used to find the j-step prediction error covariance matrix, V^j, when using repeated predictions:

$$B_1 = - A_1$$

$$B_j = - (A_j + B_1 A_{j-1} + \dots + B_{j-1} A_1)$$

and

$$V^j = V^{j-1} + B_{j-1} V^1 B'_{j-1} \ .$$

Once this matrix has been obtained, its main diagonal consists of the error variances for the variables to be predicted. These can then be used to determine confidence intervals to be placed about the forecast values.

3. Preliminary Data Analysis

Before an attempt was made to determine any MVAR models, a preliminary data analysis was performed using the 3-hourly observations (00Z, 03Z, etc.) collected during 1972-1975 for the following stations: Hannover, Bremen, Braunschweig, Boizenburg, Magdeburg, Weissen, and Wernigerode. First, the distributions of the six variables to be predicted (temperature, u- and v-components of the wind, visibility, ceiling height, and height of the first cloud layer) were determined. In Figure 1 the distribution of the 1972-1975 temperature and u-wind observations for Wernigerode are displayed with their sample means denoted by a star. The distributions shown here are typical of the temperature and u- and v-wind observations for all seven stations used in this study. As can be seen in Figure 1, these variables appear to be quite normally distributed.

On the other hand the distributions found for visibility and the cloud height variables were far from normal. In Figure 2a the distribution found for the visibilities observed at Wernigerode is shown. This distribution, which is typical of those found for the visibility and cloud height variables at all seven stations, is roughly rectangular with a sample mean of just over 9 km. However, since an MVAR model is designed to predict deviations of the variables about their sample means and since for these three variables the sample means are much larger than the low visibility and low ceiling situations that one would like to be able to predict, the following transformations were performed upon these variables in order to emphasize the variance of the low visibility (ceiling) situations:

$$V2 = \exp(-V1/2000) \qquad (3)$$

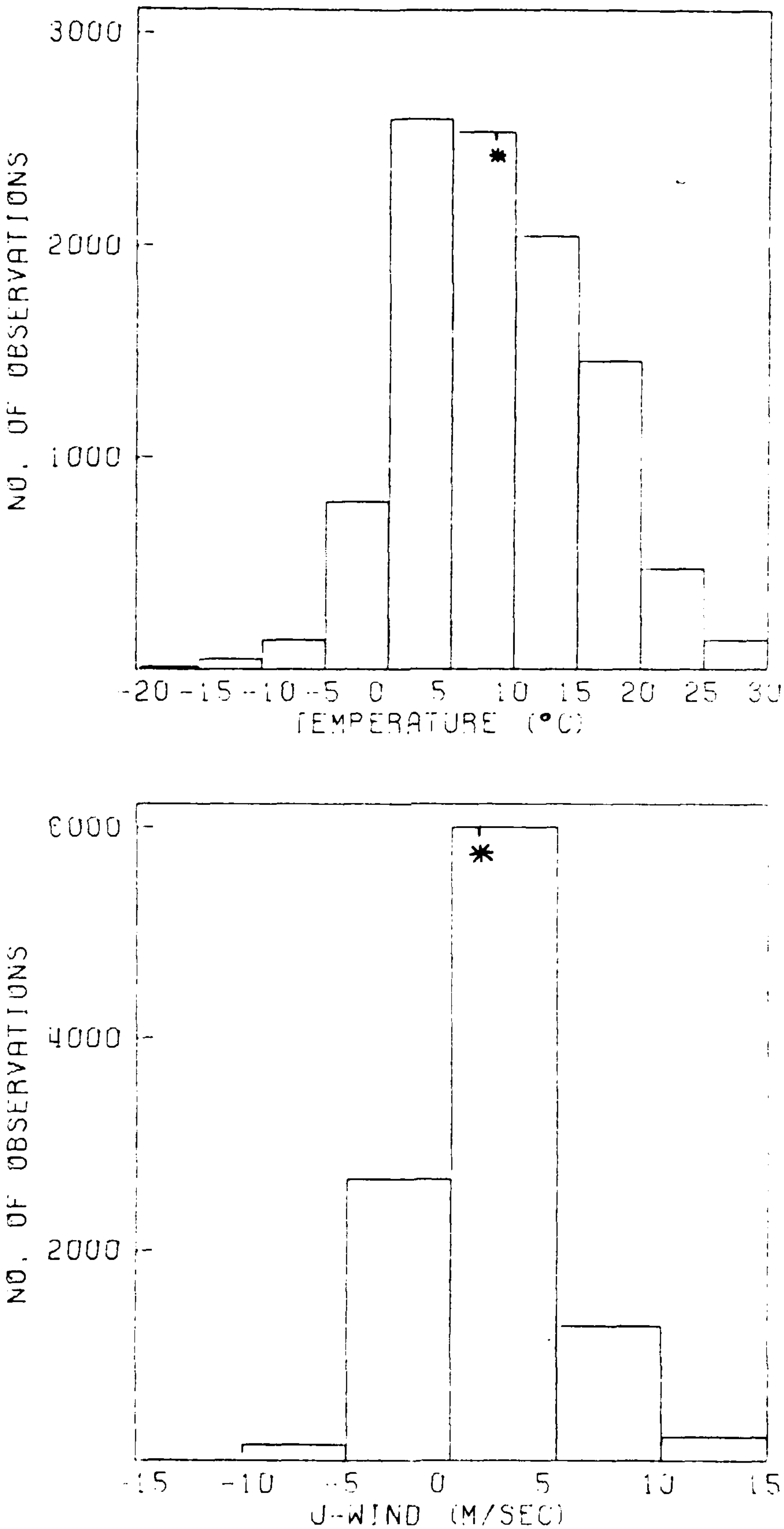

Figure 1. Distribution of 1972-1975 temperature and u-wind observations for Wernigerode.

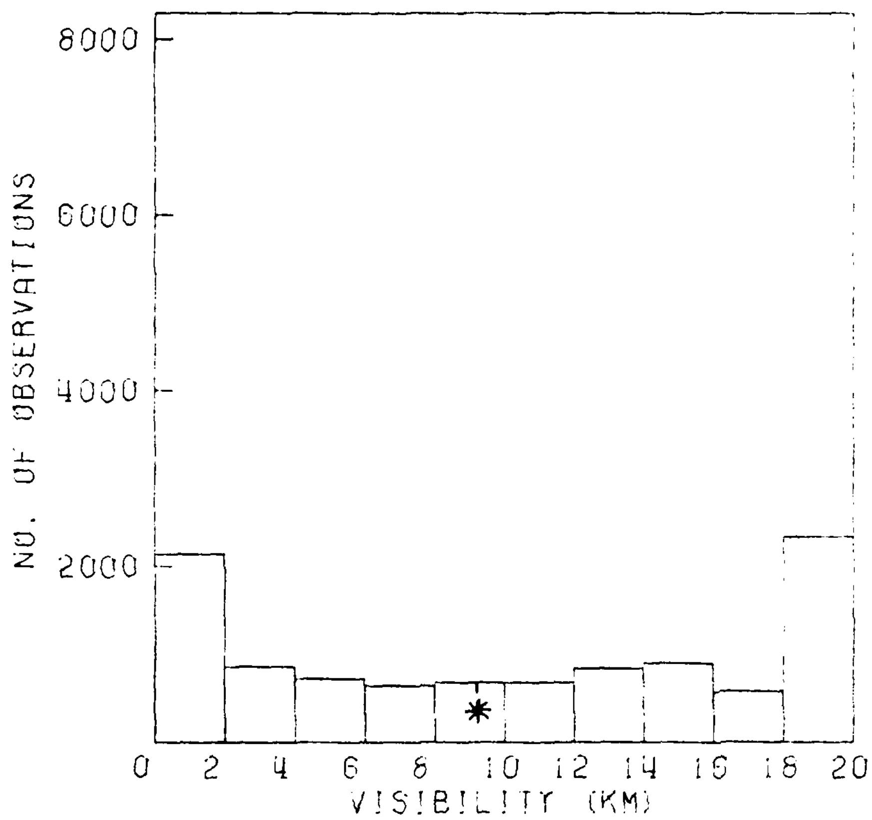

Figure 2a. Distribution of 1972-1975 visibility observations for Wernigerode.

$$C2 = \exp(-C1/1000), \qquad (4)$$

where V1 and C1 are the observed visibility and cloud height, respectively, in meters. In Figure 2b we can see the effect of this transformation upon the visibility distribution for Wernigerode. The sample mean of the transformed variable now represents a visibility of only 2.4 km. Furthermore, an observation of visibility less than 1 km will contribute more to the variance than an observation of unlimited visibility since its deviation from the sample mean will be larger. By expanding the scale for low visibilities and decreasing the scale for high visibilities, this transformation permits more precise forecasts of the poor visibility situations.

Next, monthly and hourly means were computed for all variables at all stations using the 1972-1975 observations. Table 1 summarizes the

Table 1. Variance explained by monthly and hourly means for Hannover (1972-1975).

Variable	Total Variance	Variance Explained by: Monthly Means	Percent	Hourly Means	Percent
First Cloud Layer Ht.*	.0791	.0052	6.6	.0036	4.6
Ceiling Ht.*	.0843	.0070	8.3	.0028	3.3
Temperature	53.49	32.13	60.1	4.70	8.8
Visibility*	.0331	.0021	6.3	.0013	3.9
u-wind	13.63	.79	5.8	.062	0.5
v-wind	6.08	.52	16.4	.32	0.5

* Indicates transformed variable.

results of these computations for Hannover, which again are typical of those found for the other stations. We can see that with the exception of monthly averages for temperature, only a small percent of the total variance for the six variables is explained by the annual and diurnal cycles.

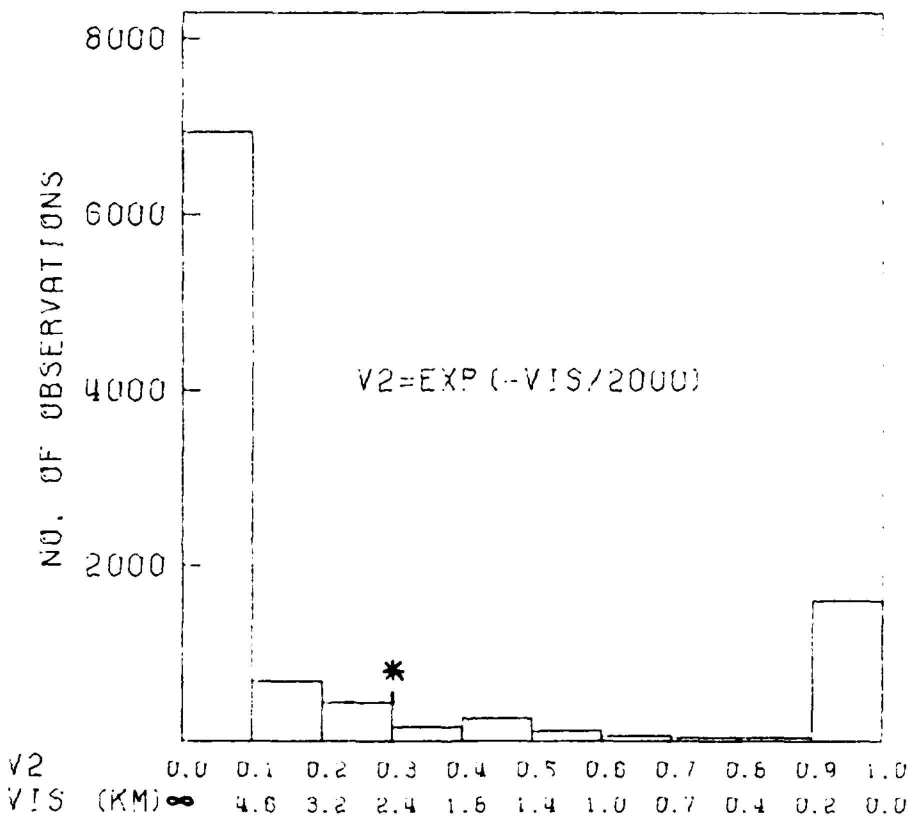

Figure 2b. Distribution of transformed 1972-1975 visibility observations for Wernigerod.

Typically, about 60 percent of the temperature variance is explained by the annual cycle. Plots of the hourly and monthly means for Hannover are displayed in Figure 3. We can see that the amplitude of the annual wave is about $8^{O}C$ while that of the diurnal wave is about $3^{O}C$. Since all seven stations display this pronounced annual wave for temperature and it explains a significant amount of the variance, its effect will be removed from the temperature data along with that of the diurnal cycle and the sample mean before any MVAR models are determined for that variable. One must be careful when attempting to fit an MVAR model to data which are highly correlated since unstable processes can be produced. In any case, it is the deviations about these very regular cycles that we are interested in forecasting, and, thus it is these deviations which we will attempt to model.

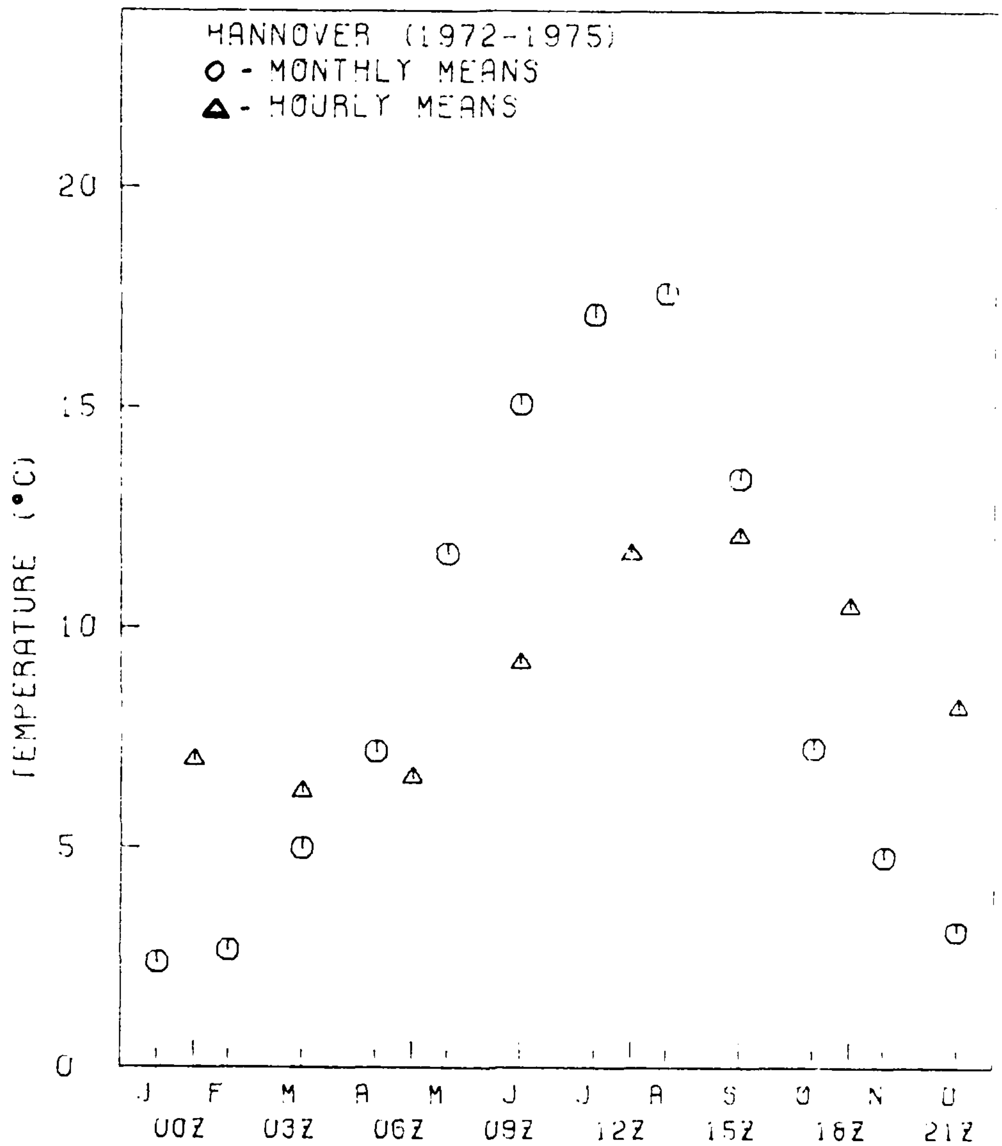

Figure 3. Monthly and hourly means computed from 1972-1975 Hannover temperatures.

4. Application and Results

Using observations collected during 1972-1974 the MVAR modeling process described in Section 2 was applied in several different ways in order to determine the best forecasting technique. Given the tactical constraint of limited computer size and storage, we will only consider MVAR forecast models of order nine or less. Thus, only a one day history of observations of the predictor variables need be stored at a time. This tactical consideration also limits the number of variables to be used by the MVAR models (not only those to be predicted but also those to aid in the prediction). For example, if an MVAR model were developed which used all of the observed variables for all stations, then it would possess 49 variables. If the model were of order nine, then nine 49 x 49 coefficient matrices would have to be stored and used in the forecast computations along with nine 49 x 1 observational vectors from the past 24 hours. This would require almost 100K bytes of storage and a comparably large number of computations required to make the forecasts. On the other hand, a model of order nine with only seven variables would require about 50 times less space and computation time.

The first type of MVAR model to be tested used the six variables to be predicted (temperature, u- and v-wind components, visibility, ceiling height, and height of the first cloud layer) along with the dew-point temperature for one station at a time. The analysis procedure outlined in Section 2 was applied using the 1972-1974 observations to calculate the lag sum matrices. The model order was restricted to be no greater than nine and this maximum was chosen in every case except for Braunschweig where an eighth order model possessed the smallest Akaike FPE parameter. The

7 x 7 coefficient matrices for each resulting station model were determined along with estimates of the one-step prediction error variance for the six variables to be forecast. We will use these estimates in order to determine the quality of the various MVAR forecast models tested here. Table 2 summarizes the results for the 7 station models. We can see that using such a

Table 2. Estimates of one-step prediction error variance and percent variance explained (in parenthesis) for the station MVAR models determined from 1972-1974 observations.

Station	Model Order	Height of 1st Cloud Layer*	Ceiling Height*	Temperature	Visibility*	u-wind	v-wind
Hannover	9	.0374 (54.7)	.0436 (48.6)	2.55 (94.8)	.0164 (52.2)	2.96 (78.8)	2.40 (63.0)
Bremen	9	.0367 (52.8)	.0436 (45.5)	2.93 (93.8)	.0194 (42.4)	3.31 (78.4)	2.99 (67.3)
Boizenburg	9	.0181 (32.2)	.0308 (35.0)	3.75 (92.4)	.0252 (46.8)	4.78 (63.9)	3.47 (48.4)
Braunschweig	8	.0296 (53.2)	.0333 (49.8)	3.12 (92.7)	.0112 (55.0)	2.82 (75.9)	2.46 (59.1)
Magdeburg	9	.0260 (36.3)	.0314 (38.8)	3.58 (93.3)	.1400 (66.7)	3.01 (72.1)	3.17 (52.0)
Wernigerode	9	.0223 (38.4)	.0264 (42.5)	3.9 (92.1)	.0332 (64.6)	3.97 (67.5)	4.16 (46.0)
Weissen	9	.0360 (33.1)	.0391 (38.8)	4.15 (92.4)	.0186 (50.4)	5.01 (67.5)	3.06 (52.9)

*Indicates transformed variable.

model we can best forecast temperatures (from 92.1 to 94.8 percent variance explained) and are least able to forecast the height of the first cloud layer (from 32.2 to 54.7 percent variance explained). One can roughly expect to explain 40%, 55%, 55%, and 70% of the variance for ceiling height, visibility, v-wind, and u-wind, respectively.

The next type of MVAR model to be investigated utilized the observations for a particular variable at all seven stations. Again the model order was restricted to nine or less and the MVAR analysis procedure was applied to the 1972-1974 observations for the six different variables to be forecast. In Table 3 the estimates of the one-step prediction error variance and the percent variance explained for the 6 variable models are displayed. In this case, as discussed in Section 3, the monthly and hourly

Table 3. Estimates of one-step prediction error variance and percent variance explained (in parenthesis) for the variable MVAR models determined from 1972-1974 observations.

Variable	Model Order	Hannover	Bremen	Boizenburg	Braunschweig	Magdeburg	Wernigerode	Weissen
Height of 1st Cloud Layer *	9	.0359 (56.5)	.0369 (52.5)	.0183 (31.5)	.0261 (58.7)	.0244 (40.2)	.0224 (38.1)	.0339 (37.0)
Ceiling Height *	9	.0419 (50.6)	.0440 (45.0)	.0298 (37.1)	.0293 (55.9)	.0282 (45.0)	.0263 (42.7)	.0367 (42.6)
Temperature	9	2.24 (95.4)	2.34 (95.0)	2.63 (94.7)	2.02 (95.3)	2.35 (95.6)	2.82 (94.3)	3.19 (94.1)
Visibility *	9	.0157 (54.2)	.0187 (44.5)	.0241 (49.2)	.0097 (61.0)	.0132 (68.6)	.0335 (64.3)	.0178 (52.5)
u-wind	9	2.51 (82.0)	3.18 (79.2)	3.85 (70.8)	2.28 (80.5)	2.33 (78.4)	3.66 (70.0)	3.88 (74.8)
v-wind	9	2.00 (69.1)	3.08 (66.3)	2.99 (55.6)	2.03 (66.3)	2.51 (62.0)	3.72 (51.7)	2.48 (61.8)

* Indicates transformed variable.

means were removed along with the sample means for the temperature observations. A comparison of Tables 2 and 3 indicates that in almost every case the percent variance explained by the variable-at-a-time MVAR models is greater than that for the station-at-a-time models. The greatest improvement is noted for the v-wind predictions where the percent variance explained is increased by as much as 10%. For the variable-at-a-time models we can expect to explain approximately 95%, 75%, 60%, 55%, 45%, and 45% of the variance, respectively, for temperature, u-wind, v-wind, visibility, ceiling height, and height of the first cloud layer.

For the first two types of MVAR models tested here the model order was limited. However, for both types, MVAR models were determined in which the maximum order permitted was 30. In these cases MVAR models whose order ranged from 25 to 30 were found to possess the minimum value of the Akaike FPE parameter. In every case though the reduction of the one-step prediction error variance over that of the ninth order models was negligible. Thus, the limitation of the model size required by the tactical situation has no detrimental effect upon the quality of the forecast models produced.

A final MVAR model was examined in which the number of variables was 21, consisting of the aforementioned seven variables for the stations, Hannover, Bremen, and Braunschweig. Again the model order was limited to nine or less and a ninth order model was chosen by the analysis procedure. Table 4 summarizes the results for this particular model.

Table 4. Estimates of one-step prediction error variance and percent variance explained (in parenthesis) for the three-station MVAR model determined from 1972-1974 observations.

Station	Height of 1st Cloud Layer*	Ceiling Height*	Temperature	Visibility*	u-wind	v-wind
Hannover	.0341 (58.7)	.0391 (53.9)	2.10 (94.7)	.0152 (55.7)	2.46 (82.3)	1.97 (69.6)
Bremen	.0348 (55.2)	.0416 (47.9)	2.31 (95.1)	.0182 (46.0)	2.97 (80.6)	2.87 (68.6)
Braunschweig	.0248 (60.8)	.0282 (57.5)	2.19 (94.9)	.0098 (60.6)	2.24 (80.8)	1.98 (67.1)

* Indicates transformed variable.

Comparing Table 4 with Table 3 one can see that this 21-variable model is only slightly better than the three respective 7-variable models. Therefore, since the variable-at-a-time models can be run using about one-tenth the computer space and time and since there is negligible improvement to be gained from the larger model, they have been chosen as the best MVAR forecast model to be used for short-range predictions in a tactical situation.

We have seen in this section how well, based on the MVAR theory described in Section 2, we can expect to forecast the six meteorological variables of interest in this study. Using the six variable-at-a-time models, whose expected performances are outlined in Table 3, and observations collected during 1976, a number of MVAR forecasts were made and compared with the observations valid at the forecast time. Assuming that the MVAR forecast models are unbiased, theoretical estimates of the root mean square errors (RMSE's) for the one-step through four-step predictions are obtained by simply taking the square root of the one-step through four-step prediction error variances. These theoretical RMSE's are then compared with the actual RMSE's computed from 3-, 6-, 9-, and 12-hour forecasts made using the six MVAR models (developed using 1972-1974 data) upon 1976 observations.

Tables 5 and 6 display the results of 48 MVAR forecasts using the ninth order variable-at-a-time models for the transformed variables height of the first cloud layer and ceiling height, respectively. We can see in Table 5 that in virtually every case the RMSE's computed from the actual MVAR forecasts were smaller than those expected from theory and in no case were they larger. The RMSE's determined from the ceiling height forecasts shown in Table 6 agree quite closely with their theoretical counterparts for four stations (Hannover, Bremen, Braunschweig, and Weissen) and are

Table 5. Comparison of theoretical forecast RMSE's (T) with those computed from actual MVAR forecasts (C) using 1976 transformed height of first cloud layer data.

Station	No. of Forecasts	RMSE's 3-hour FCST C	T	6-hour FCST C	T	9-hour FCST C	T	12-hour FCST C	T
Hannover	48	0.12	0.19	0.18	0.23	0.19	0.25	0.20	0.26
Bremen	48	0.11	0.19	0.16	0.23	0.17	0.25	0.20	0.26
Boizenburg	48	0.10	0.14	0.11	0.15	0.12	0.15	0.12	0.15
Braunschweig	48	0.13	0.16	0.14	0.19	0.20	0.21	0.17	0.22
Madgeburg	48	0.09	0.16	0.15	0.17	0.11	0.18	0.14	0.19
Wernigerode	48	0.08	0.15	0.10	0.16	0.10	0.17	0.09	0.18
Weissen	48	0.17	0.18	0.20	0.20	0.21	0.21	0.22	0.22

Table 6. Comparison of theoretical forecast RMSE's (T) with those computed from actual MVAR forecasts (C) using 1976 transformed ceiling height data.

Station	No. of Forecasts	RMSE's 3-hour FCST C	T	6-hour FCST C	T	9-hour FCST C	T	12-hour FCST C	T
Hannover	48	0.20	0.20	0.24	0.24	0.28	0.25	0.25	0.27
Bremen	48	0.22	0.21	0.26	0.24	0.27	0.25	0.28	0.27
Boizenburg	48	0.11	0.17	0.12	0.19	0.13	0.20	0.13	0.21
Braunschweig	48	0.19	0.17	0.18	0.20	0.26	0.22	0.20	0.23
Magdeburg	48	0.10	0.17	0.16	0.19	0.12	0.20	0.15	0.21
Wernigerode	48	0.08	0.16	0.10	0.18	0.10	0.19	0.10	0.20
Weissen	48	0.18	0.19	0.20	0.21	0.21	0.22	0.23	0.23

consistently smaller for the other three stations. The results for 46 MVAR forecasts for the third transformed variable, visibility, are shown in

Table 7. With the exception of those found for Boizenburg, the RMSE's computed from the forecasts agree quite well with those expected from theory.

Table 7. Comparison of theoretical forecast RMSE's (T) with those computed from actual MVAR forecasts (C) using 1976 transformed visibility data.

		RMSE's							
	No. of	3-hour FCST		6-hour FCST		9-hour FCST		12-hour FCST	
Station	Forecasts	C	T	C	T	C	T	C	T
Hannover	46	0.09	0.13	0.09	0.15	0.18	0.16	[illegible]	[illegible]
Bremen	46	0.09	0.14	0.14	0.16	0.15	0.16	0.12	[illegible]
Boizenburg	46	0.34	0.16	0.29	0.18	0.28	0.19	0.33	[illegible]
Braunschweig	46	0.10	0.10	0.09	0.12	0.21	0.13	0.15	[illegible]
Magdeburg	46	0.14	0.11	0.12	0.14	0.14	0.16	0.22	[illegible]
Wernigerode	46	0.25	0.18	0.19	0.20	0.19	0.20	0.26	[illegible]
Weissen	46	0.12	0.13	0.16	0.15	0.19	0.16	0.22	0.17

It was found that during the forecast periods, a much larger number of zero visibilities (resulting in a transformed variable value of one) were actually observed at Boizenburg than at any other station. In Figure 2b we can see that such observations would result in an increase in variance and thus in the RMSE's for the transformed visibilities.

The RMSE comparison for 58 temperature forecasts is displayed in Table 8 while those for 140 wind forecasts are shown in Tables 9 and 10. We can see in Tables 8 and 9 that the computed RMSE's are slightly larger than their theoretical counterparts for the temperature and u-wind MVAR forecasts. In no case, however, are these differences significant. The v-wind MVAR forecasts, whose RMSE's are shown in Table 10, are consistently

Table 8. Comparison of theoretical forecast RMSE's (T) with those computed from actual MVAR forecasts (C) using 1976 temperature data.

		RMSE's							
		3-hour FCST		6-hour FCST		9-hour FCST		12-hour FCST	
Station	Forecasts	C	T	C	T	C	T	C	T
Hannover	58	1.65	1.50	2.25	2.08	2.94	2.39	2.79	2.71
Bremen	58	1.71	1.53	2.07	2.02	2.45	2.31	2.72	2.57
Boizenburg	58	1.61	1.62	1.98	2.08	2.31	2.36	2.25	2.57
Braunschweig	58	1.54	1.42	2.11	1.93	2.50	2.24	2.55	2.50
Magdeburg	58	1.74	1.53	2.29	2.00	2.44	2.30	2.43	2.55
Wernigerode	58	2.18	1.68	2.53	2.18	2.82	2.49	2.81	2.72
Weissen	58	1.93	1.79	2.59	2.28	2.57	2.56	2.26	2.75

better than those expected from theory. In summary, we have seen in Tables 5 - 10 that for the most part, when tested upon 1976 observations, the forecasts produced by the six ninth order variable-at-a-time MVAR models (developed using 1972-1974 data) agree quite well with what one would expect theoretically.

Table 9. Comparison of theoretical forecast RMSE's (T) with those computed from actual MVAR forecasts (C) using 1976 u-wind data.

		RMSE's (msec^{-1})							
		3-hour FCST		6-hour FCST		9-hour FCST		12-hour FCST	
Station	Forecasts	C	T	C	T	C	T	C	T
Hannover	140	2.02	1.58	2.32	2.09	2.97	2.42	2.99	2.71
Bremen	140	2.56	1.78	2.87	2.28	3.26	2.60	3.42	2.87
Boizenburg	140	1.95	1.96	2.31	2.23	2.71	2.49	2.69	2.66
Braunschweig	140	1.74	1.51	2.31	1.95	2.74	2.26	3.01	2.50
Magdeburg	140	1.52	1.53	2.34	1.88	2.65	2.16	2.87	2.36
Wernigerode	140	2.17	1.91	2.71	2.27	2.81	2.53	2.95	2.72
Weissen	140	1.99	1.97	2.65	2.29	2.97	2.57	3.17	2.77

Table 10. Comparison of theoretical forecast RMSE's (T) with those computed from actual MVAR forecasts (C) using 1976 v-wind data.

Station	Forecasts	RMSE's ($msec^{-1}$) 3-hour FCST C	3-hour FCST T	6-hour FCST C	6-hour FCST T	9-hour FCST C	9-hour FCST T	12-hour FCST C	12-hour FCST T
Hannover	140	1.32	1.41	1.41	1.74	1.78	1.97	1.80	2.13
Bremen	140	1.83	1.75	2.13	2.17	2.48	2.41	2.62	2.62
Boizenburg	140	1.29	1.73	1.45	1.96	1.59	2.12	1.68	2.26
Braunschweig	140	1.32	1.42	1.43	1.70	1.77	1.90	1.72	[illegible]
Magdeburg	140	1.26	1.59	1.33	1.83	[illegible]	2.01	1.76	2.17
Wernigerode	140	1.90	1.93	1.94	2.18	2.25	2.34	2.05	2.47
Weissen	140	1.45	1.57	1.56	1.82	1.88	2.01	1.96	[illegible]

Finally, in the next table we will demonstrate how confidence intervals can be placed about MVAR predictions using two visibility forecasts made with the variable-at-a-time model. From the error analysis of the actual forecasts whose results are outlined in Tables 5 - 10, we conclude that in practice the MVAR models make predictions much like we would expect from theory. Confidence intervals (C.I.) to be placed about the MVAR predictions can be computed by multiplying a constant (varying in size depending on the percent C.I. desired) by the square root of the estimated forecast-step prediction error variance. Since this is equivalent to multiplying that constant by the theoretical RMSE's shown in Tables 5 - 10, we can see that, as one would expect, larger and larger C.I.'s will be determined as the forecast-step is increased.

The results of two visibility forecasts made using the variable-at-a-time MVAR model are shown in Table 11. The forecasts and confidence intervals have been transformed back into normal units (km). The 12-hour

Table 11. A comparison of MVAR visibility forecasts (F) and 80% confidence intervals (in parenthesis) with the actual observed visibilities (A).

Forecast Time - 18Z, March 29, 1976

Station	3-hour F	3-hour A	6-hour F	6-hour A	9-hour F	9-hour A	12-hour F	12-hour A
	20+	20+	7.8	20	7.1	8	5.3	7
Hannover	(3.9,20+)		(3.1,20+)		(3.0,20+)		(2.5,20+)	
	20+	20	20+	20	11	20	5.7	8
Bremen	(3.7,20+)		(3.2,20+)		(3.1,20+)		(2.6,20+)	
	7.5	18	8.2	16	6.7	12	4.5	6
Boizenburg	(3.0,20+)		(2.8,20+)		(2.6,20+)		(2.1,20+)	
	20+	20	20+	15	9	15	8.8	9
Braunschweig	(4.3,20+)		(3.8,20+)		(3.5,20+)		(3.3,20+)	
	20+	16	20+	16	6.9	12	6.5	12
Magdeburg	(4.1,20+)		(3.5,20+)		(2.9,20+)		(2.7,20+)	
	4	20	0.5	0	0.6	0	4.9	12
Wernigerode	(2.0,20+)		(0., 1.3)		(0., 1.5)		(2.1,20_)	
	20+	20	7.3	20	5.5	15	5.7	6
Weissen	(3.6,20+)		(3.0,20+)		(2.6,20+)		(2.6,20+)	

Forecast Time - 06Z, April 16, 1976

Station	3-hour F	3-hour A	6-hour F	6-hour A	9-hour F	9-hour A	12-hour F	12-hour A
	1.1	0.4	2.1	6	3	10	3.2	8
Hannover	(0.6,1.7)		(1.3,3.8)		(1.7,7.7)		(1.8,20+)	
	1.3	1.5	2.2	6	2.5	8	3.1	9
Bremen	(0.7,2.1)		(1.3,4.2)		(1.4,5.2)		(1.7,20+)	
	0.7	0	1.4	7	1.8	0	2.3	10
Boizenburg	(0.2,1.4)		(0.6,2.6)		(0.9,3.7)		(1.1,5.5)	
	0.9	0.1	1.9	6	2.3	7	3.0	6
Braunschweig	(0.5,1.3)		(1.2,2.9)		(1.5,3.8)		(1.8,6.2)	
	0.7	3.5	1.5	6	1.8	8	2.1	6
Magdeburg	(0.3,1.2)		(0.8,2.4)		(1.0,3.2)		(1.2,4.1)	
	1.8	4.5	1.8	4	3.1	6	3.2	6
Wernigerode	(0.9,3.4)		(0.8,3.8)		(1.5,20+)		(1.5,20+)	
	1.0	4	1.8	6	2.2	10	2.6	8
Weissen	(0.5,1.7)		(1.0,3.2)		(1.3,4.3)		(1.4,6.1)	

period after 18Z on March 29, 1976, was basically a time of high visibility. In this case every 80% C.I. about the MVAR forecasts included the actual visibility. It is especially notable that the model predicted very well the very low visibilities actually observed at Wernigerode 6 and 9 hours after the initial time. The 12-hour period following 06Z on April 16, 1976, was one in which visibilities were very low after 3 hours and then steadily improved over the rest of the period. The very low visibilities at the 3-hour mark were well forecast and for every station the visibilities were predicted to improve out to 12 hours. In this case the model did not improve the visibilities as fast as nature and only a few of the 80% C.I. include the actual observations. From this table we can see that the confidence intervals can probably be best used by an actual forecaster to specify a minimum expected visibility in high visibility situations and a maximum expected visibility in low visibility situations. This type of interpretation of the C.I.'s is also appropriate for the other two transformed variables (ceiling height and height of first cloud layer). The customary interpretation of the C.I.'s as a range in which we expect the variable to lie can be applied to the other three variables (temperature, u-wind, and v-wind). This range was found to be the order of $\pm 2^{\circ}C$ and ± 2 m/sec for a 3-hour forecast of temperature and the wind components, respectively. For 12-hour forecasts it was found that the temperature and wind ranges were about $\pm$ $3^{\circ}C$ and $\pm$ 3.5 m/sec, respectively.

5. Conclusions

In this study multivariate autoregressive climatological models were developed to be used for short-term forecasting of six atmospheric variables (temperature, visibility, u-wind, v-wind, ceiling height, and height of the first cloud layer) over a limited area in a tactical situation. After a preliminary data analysis it was found that the cloud-height variables and visibility could best be forecast if they were first transformed so that the variance of low ceiling and visibility situations be emphasized over that of high ceiling and visibility conditions. Various forecast models were investigated, and it was found that, given the tactical constraints, the best models were ninth order variable-at-a-time MVAR models in which an observation vector consisted of the values of the variable to be predicted at the seven German stations used in this study (Hannover, Bremen, Braunschweig, Boizenburg, Magdeburg, Wernigerode, and Weissen). The prediction error variance matrix and the coefficient matrices for each of the six variable-at-a-time MVAR forecast models are tabulated in Appendix A. Using these models one can expect to make 3-hour forecasts which explain approximately 95%, 75%, 60%, 55%, 45% and 45% of the variance, respectively, for temperature, u-wind, v-wind, visibility, ceiling height, and height of the first cloud layer.

The MVAR models were developed using data collected during 1972-1974. The models were then tested independently using 1976 observations and it was found that the actual forecast errors agree quite well with what would be theoretically predicted. Using the estimated prediction error variances, confidence intervals were determined to be placed about the MVAR forecasts. It was found that 80% C.I.'s of $\pm$ 2°C and $\pm$ 2 m/sec could be placed about the 3-hour forecasts of temperature and the wind components, respectively. Due to the variable transformation made upon the visibility and cloud height variables, it was found that the confidence intervals could be best used to determine minimum expected visibilities (or cloud heights) in high visibility (or ceiling) situations and to determine maximums in the poor visibility (low ceiling) situations.

6. References

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APPENDIX A

COVARIANCE AND COEFFICIENT MATRICES FOR THE SIX VARIABLE-AT-A-TIME MVAR MODELS

VARIABLE-AT-A-TIME MVAR MODEL FOR TEMPERATURE   MODEL ORDER IS 9

ONE-STEP PREDICTION ERROR COVARIANCE MATRIX

2.2390	1.3424	1.1723	1.3838	1.0775	1.4253	1.2331
1.3424	2.3353	1.1170	1.0036	0.7832	0.9985	0.9633
1.1723	1.1171	2.6270	1.0690	1.0708	1.1669	1.6049
1.3838	1.0037	1.0691	2.0247	1.1673	1.4253	1.2156
1.0775	0.7833	1.0708	1.1673	2.3475	1.3711	1.4996
1.4253	0.9986	1.1669	1.4253	1.3710	2.8232	1.4082
1.2331	0.9633	1.6049	1.2156	1.4995	1.4082	3.1902

COEFFICIENT MATRIX A1

-0.5150	-0.2799	-0.0838	-0.0477	0.0406	-0.2020	-0.0514
-0.2149	-0.5996	-0.0952	-0.0068	0.0339	-0.1055	-0.0354
-0.1779	-0.2456	-0.4113	0.0529	-0.0214	-0.0720	-0.1527
-0.1878	-0.1457	-0.0813	-0.4863	0.0243	-0.1508	-0.0324
-0.1544	-0.0695	-0.1085	-0.1129	-0.3041	-0.2153	-0.1029
-0.2374	-0.0825	-0.0531	-0.0294	-0.0057	-0.6194	0.0318
-0.1047	-0.0978	-0.2359	0.0111	-0.0222	-0.0851	-0.5979

COEFFICIENT MATRIX A2

0.0642	0.0889	0.0413	0.0165	0.0396	0.0200	0.0324
0.1147	0.0176	-0.0182	0.0366	0.0346	-0.0149	0.0387
0.1740	0.1104	-0.0832	-0.0680	0.0329	-0.0260	0.0518
0.1805	0.0338	-0.0096	-0.1213	0.0488	0.0105	0.0484
0.1533	0.0376	0.0342	-0.0246	-0.0134	-0.0081	0.0037
0.1592	0.0691	-0.0617	-0.0326	0.0395	-0.0502	0.0193
0.1437	0.0884	0.0181	-0.0344	0.0087	-0.0518	0.0152

COEFFICIENT MATRIX A3

0.0240	-0.0041	-0.0218	-0.0147	0.0039	-0.0099	0.0176
0.0123	-0.0380	0.0252	0.0115	-0.0219	-0.0067	0.0394
[illegible]	-0.0576	0.0139	0.0426	0.0235	0.0272	0.0578
0.0529	-0.0090	-0.0332	-0.0401	0.0372	0.0183	0.0317
-0.0263	-0.0554	-0.0134	0.0949	-0.0065	-0.0220	0.0708
[illegible]	-0.0717	-0.0132	0.0528	0.0667	0.0026	0.0647
[illegible]	-0.0431	0.0075	0.0569	0.0228	0.0070	0.0990

COEFFICIENT MATRIX A4

0.0080	-0.0069	0.0366	0.0219	0.0034	-0.0200	0.0022
0.0032	-0.0244	0.0068	0.0304	0.0061	-0.0136	0.0022
0.0449	0.0299	-0.0871	-0.0711	0.0137	-0.0658	0.0354
0.0183	0.0059	0.0311	-0.0163	-0.0134	-0.0496	-0.0041
0.0145	0.0062	0.0113	0.0112	-0.0597	-0.0106	-0.0390
-0.0433	0.0283	-0.0757	0.0028	-0.0324	-0.0400	-0.0139
0.0352	0.0291	-0.0209	-0.0149	-0.0436	-0.0429	-0.0302

COEFFICIENT MATRIX A5

-0.0925	-0.0017	0.0201	-0.0072	0.0275	-0.0197	0.0020
-0.0421	-0.0392	0.0252	-0.0013	-0.0000	-0.0097	0.0110
-0.1145	-0.0149	0.0764	0.0907	-0.0280	0.0682	-0.0268
-0.0299	-0.0002	-0.0127	-0.0614	0.0327	0.0256	0.0278
-0.0721	0.0082	0.0294	-0.0172	-0.0189	0.0523	0.0520
-0.1080	0.0418	0.1245	0.0127	-0.0167	0.0740	0.0258
-0.0977	-0.0309	0.0313	-0.0093	0.0175	0.0322	0.0209

COEFFICIENT MATRIX A6

-0.0133	-0.0410	0.0411	0.0027	-0.0148	-0.0054	-0.0022
0.0071	-0.0698	0.0277	-0.0232	-0.0138	0.0115	0.0248
0.0584	-0.0465	-0.0673	-0.0469	0.0130	-0.0806	0.0426
0.0205	-0.0224	0.0252	-0.0520	-0.0011	-0.0151	-0.0178
0.0234	-0.0542	-0.0115	0.0347	-0.0362	-0.0232	-0.0152
0.0844	-0.0893	-0.0623	-0.0166	-0.0241	-0.1493	0.0339
0.0143	-0.0217	0.0414	0.0484	-0.0351	-0.0279	-0.0326

COEFFICIENT MATRIX A7

-0.0029	-0.0365	-0.0428	0.0541	-0.0222	0.0434	-0.0101
0.0598	-0.0557	-0.0800	0.0474	-0.0425	0.0608	-0.0137
-0.0289	-0.0335	-0.0113	0.0385	-0.0367	0.1244	-0.0453
0.0060	-0.0338	-0.0010	0.0289	-0.0220	0.0456	0.0024
-0.0139	-0.0409	0.0244	0.0503	-0.0450	0.0760	-0.0132
-0.0326	-0.0078	-0.0146	0.0565	-0.0087	0.0698	-0.0249
-0.0394	-0.0672	-0.0108	0.0475	-0.0163	0.1248	-0.0724

COEFFICIENT MATRIX A8

-0.0956	-0.0360	-0.0136	-0.0697	-0.0575	-0.0245	-0.0712
-0.0491	-0.0596	-0.0064	-0.0547	-0.0622	-0.0653	-0.0334
-0.0284	-0.0664	-0.0779	0.0103	-0.0400	-0.0977	-0.0461
-0.0252	-0.0158	-0.0302	-0.1280	-0.0823	-0.0457	-0.0497
-0.0514	-0.0164	-0.0389	-0.0590	-0.1082	-0.0982	-0.0820
-0.0771	0.0069	0.0145	-0.0757	-0.1425	-0.0459	-0.0456
-0.1077	-0.0097	-0.0354	-0.0592	-0.0799	-0.0779	-0.1176

COEFFICIENT MATRIX A9

0.0553	0.0798	0.0320	0.0306	0.0364	0.0533	0.0426
0.0869	0.0310	0.0551	0.0102	0.0079	0.0996	0.0118
0.0992	0.0506	0.0521	-0.0242	0.0146	0.0755	0.0520
0.0749	0.0557	0.0560	-0.0012	0.0537	0.0692	0.0208
0.1017	0.0225	0.0682	0.0192	0.0225	0.0973	0.0509
0.1518	0.0444	0.0368	0.0044	0.0384	0.0340	0.0589
0.1420	0.0514	0.0778	0.0082	0.0191	0.0947	0.0559

VARIABLE-AT-A-TIME MVAR MODEL FOR U-WIND MODEL ORDER IS 9

ONE-STEP PREDICTION ERROR COVARIANCE MATRIX

2.5136	1.3577	0.7470	1.1605	0.7448	0.9897	0.6056
1.3577	3.1844	0.8616	0.9717	0.5516	0.7826	0.6750
0.7471	0.8617	3.8494	0.6696	0.7303	0.5848	0.9971
1.1606	0.9717	0.6695	2.2772	0.8118	0.9386	0.5583
0.7448	0.5516	0.7303	0.8118	2.3347	0.8537	0.7419
0.9897	0.7827	0.5848	0.9385	0.8536	3.6600	0.5087
0.6056	0.6750	0.9971	0.5583	0.7419	0.5087	3.8797

COEFFICIENT MATRIX A1

-0.4055	-0.3341	-0.0295	-0.1455	-0.0714	-0.1141	-0.0277
-0.2407	-0.5994	-0.0417	-0.0948	0.0116	-0.0299	-0.0189
-0.1467	-0.2720	-0.2264	-0.0510	-0.0798	-0.0474	-0.0961
-0.2544	-0.2311	-0.0330	-0.3417	-0.0463	-0.1305	-0.0141
-0.2349	-0.1071	-0.0387	-0.1028	-0.3061	-0.1609	-0.0543
-0.2357	-0.1238	-0.0290	-0.0479	-0.0932	-0.4301	-0.0128
-0.1582	-0.2172	-0.1432	-0.0874	-0.1719	-0.0470	-0.2457

COEFFICIENT MATRIX A2

-0.0080	0.0581	0.0180	0.0174	0.0125	0.0595	0.0199
0.0491	-0.0430	0.0205	0.0535	0.0471	0.0314	0.0047
0.0075	0.0120	-0.1045	-0.0023	0.0619	0.0177	0.0094
0.0512	0.1064	-0.0077	-0.1098	0.0066	0.0564	-0.0049
0.0414	0.0627	-0.0246	0.0138	-0.0478	0.0152	-0.0005
0.0866	0.0273	-0.0111	0.0006	0.0458	-0.0833	0.0218
0.0629	0.0296	-0.0358	-0.0126	-0.0116	0.0691	-0.0518

COEFFICIENT MATRIX A3

0.0477	-0.0020	0.0091	0.0094	-0.0027	-0.0165	-0.0013
0.0291	-0.0370	0.0251	0.0404	0.0112	-0.0030	-0.0153
0.0269	0.0130	-0.0481	0.0176	-0.0011	0.0569	-0.0250
0.0754	-0.0046	0.0231	-0.0246	0.0279	-0.0066	0.0118
-0.0132	0.0307	0.0182	0.0715	-0.0062	-0.0065	-0.0021
0.0661	-0.0107	-0.0140	0.0422	0.0350	-0.0608	0.0077
-0.0226	0.0237	0.0172	0.0324	0.0597	0.0106	-0.0311

COEFFICIENT MATRIX A4

-0.0268	-0.0154	0.0293	-0.0299	0.0155	0.0369	0.0237
-0.0157	-0.0432	0.0154	0.0103	-0.0023	0.0033	0.0075
0.0091	-0.0108	-0.0490	0.0135	-0.0114	-0.0088	0.0135
-0.0254	0.0006	0.0221	-0.0672	0.0129	0.0175	-0.0060
-0.0387	0.0006	-0.0145	-0.0039	-0.0218	-0.0020	-0.0032
-0.0165	-0.0304	0.0464	-0.0020	-0.0038	-0.0007	0.0075
0.0082	0.0172	0.0341	-0.0046	-0.1643	-0.0032	-0.0369

COEFFICIENT MATRIX A5

-0.0448	0.0321	-0.0225	0.0272	-0.0085	-0.0072	-0.0111
-0.0182	0.0039	0.0045	0.0199	0.0018	0.0004	-0.0039
-0.0468	0.0395	0.0144	-0.0129	0.0481	0.0196	0.0215
0.0215	0.0375	-0.0011	-0.0141	0.0321	-0.0114	0.0225
-0.0147	0.0142	0.0173	0.0547	-0.0115	-0.0199	0.0188
0.0223	-0.0162	0.0144	0.0219	-0.0109	-0.0363	0.0072
0.0039	0.0202	0.0155	0.0376	0.0638	-0.0046	-0.0167

COEFFICIENT MATRIX A6

0.0055	-0.0258	0.0190	-0.0018	-0.0172	-0.0085	-0.0046
-0.0140	-0.0432	0.0188	-0.0231	-0.0050	0.0017	0.0080
0.0589	0.0006	-0.0281	-0.0538	-0.0589	-0.0130	0.0125
0.0228	-0.0315	0.0269	-0.0719	-0.0252	-0.0009	-0.0034
0.0381	0.0182	-0.0098	-0.0497	-0.0267	0.0174	-0.0141
0.0398	0.0072	-0.0049	-0.0118	-0.0572	-0.0224	0.0030
0.0228	-0.0110	-0.0011	-0.0349	-0.0219	0.0214	-0.0224

COEFFICIENT MATRIX A7

-0.0298	0.0086	-0.0111	-0.0251	0.0295	-0.0080	-0.0244
-0.0162	-0.0088	-0.0249	-0.0068	0.0548	-0.0171	-0.0347
-0.0489	0.0186	-0.0437	0.0261	0.0083	0.0150	-0.0074
-0.0105	0.0144	-0.0115	-0.0448	0.0281	0.0318	-0.0120
-0.0763	0.0255	-0.0211	0.0390	0.0057	-0.0071	0.0006
0.0007	-0.0319	-0.0396	0.0076	0.0229	-0.0081	-0.0119
-0.0496	0.0135	-0.0132	-0.0086	0.0305	-0.0133	-0.0208

COEFFICIENT MATRIX A8

0.0021	0.0168	-0.0094	-0.0379	-0.0445	-0.0104	-0.0001
0.0097	-0.0021	-0.0125	-0.0654	-0.0207	0.0045	-0.0000
0.0075	0.0203	-0.0400	-0.0348	-0.0200	-0.0050	-0.0134
-0.0246	-0.0022	-0.0419	-0.0412	-0.0549	-0.0281	-0.0163
0.0001	0.0049	-0.0082	-0.0233	-0.0463	-0.0154	-0.0171
0.0020	0.0119	-0.0180	-0.0249	-0.0120	-0.0521	0.0042
-0.0064	0.0272	-0.0120	-0.0476	-0.0252	0.0106	-0.0236

COEFFICIENT MATRIX A9

-0.0081	0.0059	-0.0103	0.0889	0.0334	0.0131	-0.0060
0.0318	-0.0134	-0.0012	0.0670	0.0375	-0.0105	-0.0036
0.0088	0.0152	0.0068	0.0729	0.0154	0.0097	0.0076
0.0161	0.0444	0.0052	0.0427	0.0366	0.0375	0.0094
-0.0015	0.0165	-0.0093	0.0781	0.0368	0.0154	0.0058
-0.0197	0.0174	-0.0024	0.0786	0.0335	-0.0125	0.0194
0.0198	0.0032	0.0103	0.0458	0.0264	0.0465	-0.0012

VARIABLE-AT-A-TIME MVAR MODEL FOR V-WIND MODEL ORDER IS 9

ONE-STEP PREDICTION ERROR COVARIANCE MATRIX

2.0004	0.8956	0.5895	0.7087	0.5176	0.5277	0.4520
0.8955	3.0762	0.5891	0.4587	0.4081	0.3197	0.4337
0.5895	0.5891	2.9894	0.5059	0.4896	0.2117	0.5842
0.7087	0.4587	0.5059	2.0322	0.6705	0.5178	0.5673
0.5176	0.4081	0.4896	0.6705	2.5116	0.6577	0.6009
0.5277	0.3197	0.2117	0.5178	0.6577	3.7166	0.4353
0.4520	0.4338	0.5842	0.5673	0.6009	0.4353	[illegible]

COEFFICIENT MATRIX A1

-0.3342	-0.3204	-0.0893	-0.0854	-0.0345	-0.0291	[illegible]
-0.1306	-0.6586	-0.0335	-0.0496	-0.0284	0.0162	[illegible]
-0.1214	-0.2677	-0.2575	-0.0820	-0.0660	-0.0229	[illegible]
-0.2151	-0.1891	-0.0941	-0.2721	-0.0707	-0.0367	[illegible]
-0.1640	-0.1425	-0.0833	-0.1899	-0.2004	[illegible]	[illegible]
-0.1973	-0.1506	-0.0778	-0.0992	-0.0671	-0.3548	[illegible]
-0.1621	-0.1806	-0.1309	-0.1272	-0.0732	-0.0435	[illegible]

COEFFICIENT MATRIX A2

-0.0056	0.0325	0.0315	-0.0340	0.0065	-0.0007	0.0052
0.0356	-0.0160	0.0278	0.0284	-0.0067	-0.0059	0.0371
0.0833	0.0584	-0.0877	-0.0342	-0.0100	0.0009	0.0244
0.0261	0.0579	0.0308	-0.0791	0.0007	0.0009	0.0036
0.0104	0.0682	0.0152	0.0018	-0.0284	0.0214	0.0087
-0.0228	0.0656	0.0278	0.0783	0.0275	-0.0638	-0.0121
0.0409	0.0357	0.0153	-0.0127	-0.0096	0.0216	-0.0428

COEFFICIENT MATRIX A3

-0.0017	0.0574	0.0284	-0.0081	0.0183	-0.0007	-0.0160
-0.0064	-0.0177	0.0256	0.0170	0.0293	0.0099	-0.0128
0.0099	0.0302	-0.0459	0.0005	0.0336	0.0287	-0.0080
0.0301	0.0472	0.0306	-0.0212	0.0224	0.0127	0.0041
0.0225	0.0198	0.0162	-0.0085	-0.0404	0.0280	-0.0042
-0.0034	0.0453	0.0034	0.0218	-0.0167	-0.0177	0.0184
0.0242	0.0256	-0.0039	-0.0132	0.0096	0.0174	-0.0085

COEFFICIENT MATRIX A4

-0.0236	0.0071	0.0011	-0.0063	-0.0128	-0.0152	0.0044
-0.0106	-0.0060	0.0270	0.0038	-0.0036	0.0033	0.0138
0.0025	0.0100	-0.0420	-0.0109	-0.0117	0.0134	0.0155
-0.0129	0.0040	-0.0203	-0.0313	-0.0170	-0.0091	-0.0109
0.0101	-0.0116	0.0174	-0.0158	-0.0042	0.0010	-0.0003
-0.0053	-0.0448	0.0275	0.0373	-0.0094	-0.0129	0.0016
0.0114	0.0020	-0.0011	-0.0099	-0.0115	-0.0026	-0.0056

COEFFICIENT MATRIX A5

-0.0069	0.0035	0.0215	-0.0186	0.0115	0.0020	0.0239
0.0104	-0.0336	0.0057	-0.0020	0.0125	0.0086	0.0101
-0.0121	0.0314	-0.0472	0.0016	0.0090	0.0331	0.0097
0.0043	0.0057	0.0260	0.0030	0.0327	0.0286	-0.0238
-0.0127	-0.0180	0.0186	-0.0089	-0.0064	0.0130	-0.0163
-0.0280	-0.0064	0.0028	-0.0157	0.0343	0.0068	-0.0290
0.0000	-0.0069	0.0166	0.0123	0.0023	0.0248	-0.0068

COEFFICIENT MATRIX A6

-0.0037	-0.0127	0.0210	-0.0232	0.0106	-0.0079	0.0159
-0.0167	-0.0399	-0.0036	-0.0265	0.0224	0.0130	0.0067
0.0016	0.0063	-0.0415	-0.0048	0.0172	-0.0049	0.0214
0.0052	-0.0124	-0.0179	-0.0345	0.0019	0.0097	-0.0002
0.0076	0.0060	-0.0147	-0.0128	0.0013	-0.0070	0.0353
-0.0137	0.0120	0.0088	-0.0069	0.0189	-0.0132	0.0490
0.0098	-0.0169	-0.0187	-0.0255	0.0085	-0.0005	0.0129

COEFFICIENT MATRIX A7

-0.0290	-0.0063	-0.0177	-0.0269	0.0056	0.0090	-0.0148
-0.0026	-0.0264	-0.0151	-0.0311	0.0114	0.0030	-0.0080
-0.0196	-0.0179	-0.0245	-0.0351	-0.0033	-0.0157	-0.0085
-0.0245	0.0056	-0.0144	-0.0297	0.0023	-0.0079	0.0002
-0.0181	0.0070	-0.0062	-0.0181	-0.0282	-0.0104	-0.0052
-0.0016	-0.0036	-0.0085	-0.0606	0.0279	-0.0553	-0.0498
-0.0175	-0.0083	-0.0075	0.0028	-0.0080	-0.0090	-0.0117

COEFFICIENT MATRIX A8

-0.0033	0.0189	-0.0198	-0.0384	-0.0166	-0.0085	0.0097
-0.0050	-0.0459	0.0117	-0.0132	-0.0241	0.0067	0.0039
0.0428	0.0085	-0.0308	-0.0358	-0.0390	0.0027	-0.0067
-0.0046	0.0146	-0.0358	-0.0409	-0.0354	-0.0164	-0.0018
-0.0050	0.0167	-0.0262	-0.0015	-0.0292	0.0007	-0.0032
0.0681	0.0169	-0.0238	-0.0095	0.0130	-0.0763	0.0063
0.0155	0.0087	-0.0180	-0.0325	-0.0276	-0.0139	-0.0061

COEFFICIENT MATRIX A9

0.0251	0.0302	0.0096	-0.0255	0.0128	-0.0001	0.0178
0.0359	0.0198	0.0058	-0.0274	0.0127	-0.0091	0.0255
0.0644	0.0422	-0.0255	0.0033	0.0041	-0.0008	0.0191
0.0357	0.0472	0.0195	0.0156	0.0039	-0.0078	0.0146
0.0250	0.0454	-0.0018	-0.0074	0.0108	-0.0055	0.0110
0.0162	0.0448	0.0169	0.0025	-0.0187	-0.0113	0.0225
0.0367	0.0289	0.0098	0.0131	0.0121	0.0034	-0.0084

VARIABLE-AT-A-TIME MVAR MODEL FOR VISIBILITY MODEL ORDER [illegible]

ONE-STEP PREDICTION ERROR COVARIANCE MATRIX

0.0157	0.0050	0.0033	0.0052	0.0027	0.0016	0.0030
0.0050	0.0187	0.0035	0.0023	0.0016	0.0011	0.0024
0.0033	0.0035	0.0241	0.0024	0.0040	0.0012	0.0065
0.0052	0.0023	0.0024	0.0097	0.0030	0.0018	0.0019
0.0027	0.0016	0.0040	0.0030	0.0132	0.0018	0.00[illegible]
0.0016	0.0011	0.0012	0.0018	0.0018	0.0335	0.000[illegible]
0.0030	0.0024	0.0065	0.0019	0.0034	0.0003	0.017[illegible]

COEFFICIENT MATRIX A1

-0.4529	-0.1795	-0.0362	-0.1164	-0.0430	-0.0339	-0.04[illegible]
-0.1795	-0.4523	-0.0298	0.0199	-0.0325	-0.0183	-0.0[illegible]
-0.0864	-0.1396	-0.4259	-0.0256	-0.0959	-0.0051	-0.1359
-0.2151	-0.1018	-0.0162	-0.3845	-0.0901	-0.0316	-0.0366
-0.1393	-0.0449	-0.0438	-0.0984	-0.5623	-0.0244	-0.10[illegible]
-0.0476	0.0182	0.0101	-0.1014	-0.1071	-0.4005	0.018[illegible]
-0.0497	-0.0900	-0.1223	-0.0033	-0.0854	0.0034	-0.[illegible]

COEFFICIENT MATRIX A2

0.0312	0.0495	0.0288	0.0392	-0.0098	-0.0028	0.0327
0.0106	0.0236	0.0188	0.0197	-0.0234	-0.0041	0.0221
0.1067	0.0111	-0.0107	0.0422	0.0034	-0.0092	0.0302
0.0321	0.0600	0.0097	0.0263	0.0087	-0.0043	0.0182
0.0581	0.0546	0.0238	0.0501	-0.0627	-0.0147	0.0227
0.0252	-0.0080	-0.0202	-0.0508	-0.0178	-0.0022	0.0223
0.0335	0.0423	0.0250	0.0271	0.0029	-0.0063	-0.0123

COEFFICIENT MATRIX A3

-0.0059	0.0078	-0.0060	-0.0135	-0.0026	0.0194	0.0130
0.0101	-0.0096	0.0053	-0.0205	0.0122	0.0264	-0.0041
0.0262	-0.0280	0.0101	-0.0591	0.0121	0.0341	0.0001
-0.0116	0.0021	0.0004	-0.0300	-0.0083	0.0099	0.0084
0.0214	-0.0210	0.0083	0.0094	-0.0071	0.0129	0.0133
0.0238	0.0122	0.0119	-0.0454	0.0368	0.0570	0.0025
0.0294	-0.0003	-0.0027	-0.0288	0.0122	0.0192	-0.0027

COEFFICIENT MATRIX A4

0.0051	-0.0189	0.0137	0.0169	0.0076	-0.0051	0.0027
-0.0173	-0.0263	0.0220	0.0037	0.0152	-0.0113	-0.0028
0.0080	-0.0323	0.0117	-0.0054	-0.0321	-0.0010	-0.0043
0.0133	0.0024	-0.0051	-0.0054	0.0194	-0.0097	-0.0121
0.000[illegible]	-0.0068	-0.0114	-0.0265	-0.0380	0.0024	0.0016
0.0252	0.0044	0.0012	0.0321	0.0337	-0.0724	-0.0027
0.0268	-0.0208	-0.0092	-0.0316	-0.0064	-0.0022	0.0078

COEFFICIENT MATRIX A5

-0.0337	-0.0031	-0.0277	0.0130	-0.0033	0.0076	0.0060
0.0053	-0.0279	-0.0213	-0.0086	0.0277	0.0055	0.0235
0.0012	0.0118	-0.0432	0.0108	0.0558	0.0066	0.0045
-0.0351	-0.0203	0.0109	0.0189	-0.0266	0.0063	0.0082
-0.0022	-0.0056	-0.0013	0.0173	0.0230	-0.0032	0.0069
-0.0190	-0.0048	0.0099	0.0221	-0.0148	0.0681	[illegible]
0.0090	-0.0130	0.0071	-0.0043	0.0091	0.0098	[illegible]

COEFFICIENT MATRIX A6

-0.0117	-0.0273	0.0225	0.0068	-0.0016	0.0089	0.0006
0.0290	-0.0482	0.0105	-0.0235	-0.0037	0.0140	0.0047
0.0286	-0.0182	-0.0066	-0.0061	-0.0426	0.0119	-0.0058
0.0181	-0.0036	-0.0180	-0.0442	0.0306	0.0045	0.0123
0.0100	0.0012	0.0190	-0.0358	-0.0473	-0.0020	-0.0003
-0.0149	0.0065	-0.0286	0.0014	-0.0022	0.0074	-0.0168
0.0011	0.0000	0.0070	0.0295	-0.0241	0.0016	0.0076

COEFFICIENT MATRIX A7

-0.0218	-0.0231	-0.0113	-0.0650	-0.0305	-0.0116	-0.0240
-0.0198	-0.0080	0.0058	0.0036	-0.0407	-0.0102	-0.0031
-0.0153	-0.0199	-0.0544	-0.0113	-0.0084	-0.0122	0.0023
0.0171	-0.0176	0.0094	-0.0130	-0.0300	-0.0154	-0.0104
-0.0002	-0.0206	-0.0127	-0.0025	0.0265	-0.0052	0.0109
0.0366	-0.0426	-0.0256	0.0283	0.0289	-0.1139	-0.0325
-0.0337	-0.0458	-0.0287	0.0057	-0.0175	-0.0081	-0.0307

COEFFICIENT MATRIX A8

-0.0584	-0.0131	-0.0045	-0.0369	-0.0499	0.0047	-0.0477
-0.0444	-0.0376	-0.0311	-0.0279	-0.0441	0.0145	-0.0579
-0.0507	-0.0395	-0.0262	0.0249	-0.0505	0.0083	-0.0296
-0.0389	-0.0168	-0.0310	-0.0312	-0.0621	0.0175	-0.0570
-0.0242	-0.0227	-0.0038	-0.0559	-0.1144	-0.0008	-0.0818
0.0009	-0.0097	0.0242	0.0270	-0.0067	-0.6131	0.0001
-0.0151	-0.0574	-0.0000	-0.0263	-0.0755	0.0029	-0.0942

COEFFICIENT MATRIX A9

0.0212	0.0478	0.0338	0.0337	0.0678	0.0052	0.0304
0.0401	0.0287	0.0357	0.0184	0.0578	-0.0030	0.0102
0.0335	0.0287	0.0453	0.0284	0.0258	-0.0143	0.0250
0.0207	0.0422	0.0304	0.0252	0.0459	0.0120	0.0334
0.0034	0.0438	0.0259	0.0789	0.0535	0.0211	0.0407
0.0292	0.0375	0.0067	0.0244	0.0894	0.2071	-0.0277
0.0490	0.0420	0.0373	0.0160	0.0640	-0.0203	0.0549

VARIABLE-AT-A-TIME MVAR MODEL FOR CEILING   MODEL ORDER IS [illegible]

ONE-STEP PREDICTION ERROR COVARIANCE MATRIX

0.0419	0.0122	0.0056	0.0129	0.0046	0.0054	[illegible]
0.0122	0.0440	0.0069	0.0061	0.0032	0.0025	0.0038
0.0056	0.0069	0.0298	0.0037	0.0049	0.0040	0.0081
0.0129	0.0061	0.0037	0.0293	0.0054	0.0049	0.0046
0.0046	0.0032	0.0049	0.0054	0.0282	0.0068	0.0058
0.0054	0.0025	0.0040	0.0049	0.0068	0.0263	[illegible]
0.0051	0.0039	0.0081	0.0046	0.0058	0.0035	[illegible]

COEFFICIENT MATRIX A1

-0.3669	-0.2442	-0.0490	-0.1490	-0.0319	-0.0802	[illegible]
-0.1482	-0.4505	-0.1182	-0.0433	-0.0020	-0.0702	0.0451
-0.0656	-0.1360	-0.3331	0.0043	-0.0576	-0.0620	[illegible]
-0.2590	-0.1123	-0.0551	-0.3123	-0.0449	-0.0472	[illegible]
-0.0983	-0.0400	-0.0549	-0.1023	-0.3246	-0.1920	[illegible]
-0.0818	-0.0179	-0.0252	-0.0978	-0.0126	-0.4082	[illegible]
-0.1028	-0.0754	-0.0882	-0.0555	-0.1020	-0.0436	[illegible]

COEFFICIENT MATRIX A2

0.0042	-0.0190	-0.0373	0.0226	-0.0225	0.0657	0.0026
0.0189	-0.0555	-0.0384	0.0381	0.0074	0.0049	0.0009
0.0373	-0.0198	-0.0919	0.0274	-0.0405	0.0047	0.0049
0.0270	-0.0301	0.0095	-0.0049	0.0075	0.0254	0.0005
0.0378	0.0067	-0.0553	0.0026	-0.0279	-0.0055	0.0338
0.0205	-0.0013	-0.0082	0.0091	0.0203	-0.1062	0.0007
0.0319	0.0176	-0.0663	0.0036	0.0297	0.0399	-0.0228

COEFFICIENT MATRIX A3

0.0102	0.0097	-0.0080	0.0106	0.0057	-0.0021	0.0286
0.0147	0.0124	-0.0201	0.0044	-0.0036	0.0299	-0.0109
0.0446	0.0211	0.0028	0.0130	-0.0351	0.0413	-0.0018
0.0012	0.0049	0.0207	-0.0089	-0.0123	0.0204	-0.0107
0.0280	0.0167	0.0468	-0.0072	-0.0163	-0.0047	0.0324
0.0058	-0.0042	-0.0436	-0.0016	-0.0097	-0.0041	0.0574
0.0065	0.0115	0.0140	0.0146	-0.0234	0.0156	-0.0327

COEFFICIENT MATRIX A4

0.0059	-0.0026	0.0260	-0.0174	-0.0208	0.0025	-0.0164
-0.0021	-0.0258	-0.0109	-0.0316	-0.0211	0.0132	0.0291
0.0139	-0.0148	-0.0535	0.0129	-0.0156	-0.0155	0.0081
0.0296	0.0030	-0.0015	0.0178	-0.0187	-0.0251	-0.0173
0.0083	-0.0072	-0.0304	0.0067	-0.0520	-0.0470	0.0030
0.0050	-0.0035	0.0180	0.0145	-0.0289	-0.0633	-0.0521
0.0034	-0.0007	-0.0677	0.0420	0.0068	-0.0626	-0.0012

COEFFICIENT MATRIX A5

-0.0258	-0.0080	0.0243	0.0177	-0.0141	-0.0044	-0.0064
-0.0126	-0.0045	0.0573	0.0180	-0.0220	-0.0085	-0.0074
-0.0137	0.0251	0.0280	-0.0072	0.0035	0.0355	0.0028
-0.0357	0.0206	0.0396	0.0130	-0.0050	0.0103	-0.0011
-0.0469	0.0111	0.0492	0.0384	0.0031	0.0138	0.0174
0.0205	0.0049	0.0358	-0.0074	-0.0466	0.0373	0.0690
-0.0024	-0.0158	0.0125	0.0125	-0.0039	0.0409	0.0033

COEFFICIENT MATRIX A6

-0.0409	0.0127	0.0017	-0.0068	0.0077	0.0123	-0.0184
0.0030	-0.0129	-0.0476	-0.0063	0.0150	0.0391	-0.0077
0.0039	-0.0269	-0.0142	0.0024	0.0288	0.0100	0.0001
-0.0099	-0.0225	0.0379	0.0147	-0.0094	-0.0047	-0.0067
0.0136	-0.0008	-0.0142	0.0083	-0.0084	-0.0026	-0.0175
-0.0106	0.0163	-0.0258	0.0084	0.0209	0.0064	-0.0186
0.0090	0.0067	0.0179	-0.0467	0.0006	0.0108	-0.0056

COEFFICIENT MATRIX A7

0.0020	-0.0326	0.0421	-0.0247	0.0056	-0.0042	-0.0241
0.0178	-0.0102	0.0666	-0.0254	-0.0208	-0.0093	-0.0449
-0.0077	0.0076	-0.0066	0.0142	-0.0167	-0.0272	-0.0271
-0.0174	-0.0298	0.0091	-0.0282	0.0092	0.0388	-0.0042
-0.0201	-0.0255	0.0191	0.0180	-0.0118	0.0257	0.0056
0.0001	-0.0313	-0.0179	-0.0033	-0.0051	-0.0243	-0.0134
0.0038	-0.0042	0.0111	0.0210	-0.0238	0.0001	-0.0382

COEFFICIENT MATRIX A8

-0.0108	-0.0034	-0.0158	-0.0328	-0.0495	0.0047	-0.0077
-0.0317	-0.0179	-0.0119	-0.0009	-0.0267	-0.0204	0.0092
0.0206	-0.0042	-0.0299	-0.0239	-0.0192	0.0135	-0.0072
-0.0102	0.0174	-0.0062	-0.0476	-0.0580	0.0152	-0.0335
0.0041	0.0093	-0.0100	-0.0173	-0.0202	-0.0168	-0.0050
-0.0103	0.0031	-0.0097	0.0097	-0.0189	-0.0231	-0.0072
-0.0038	0.0118	0.0025	-0.0168	-0.0096	0.0017	-0.0467

COEFFICIENT MATRIX A9

0.0223	0.0107	0.0203	0.0129	0.0198	-0.0017	0.0307
0.0014	0.0044	0.0180	0.0049	-0.0149	0.0238	0.0303
0.0027	-0.0012	0.0073	-0.0008	0.0259	-0.0118	0.0038
0.0310	0.0085	0.0433	0.0056	0.0125	0.0076	0.0076
0.0044	0.0091	-0.0164	0.0101	-0.0030	0.0063	0.0089
-0.0006	0.0232	0.0161	0.0095	0.0329	-0.0301	0.0104
-0.0056	-0.0096	0.0093	0.0188	0.0395	-0.0137	-0.0043

ONE-STEP PREDICTION ERROR COVARIANCE MATRIX

0.0359	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.0132	0.0269	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.0030	0.0043	0.0183	0.0023	0.0026	0.0020	0.0041
0.0126	0.0065	0.0023	0.0061	0.0043	[illegible]	[illegible]
0.0037	0.0020	0.0026	[illegible]	[illegible]	[illegible]	[illegible]
0.0042	[illegible]	0.0020	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

COEFFICIENT MATRIX A1

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-0.0312	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-0.2619	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-0.0733	-0.0293	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-0.0863	0.0056	-0.0759	[illegible]	[illegible]	[illegible]	[illegible]
-0.0879	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

COEFFICIENT MATRIX A2

[illegible]	-0.0205	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	-0.0255	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.0265	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.0174	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.0169	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

COEFFICIENT MATRIX A3

[illegible]	0.0083	-0.0044	0.0213	[illegible]	0.0303	0.0241
[illegible]	[illegible]	-0.0260	[illegible]	[illegible]	0.0032	[illegible]
0.0203	[illegible]	-0.0016	-0.0109	-0.0120	0.0216	0.0168
[illegible]	[illegible]	-0.0090	-0.0154	0.0079	0.0176	0.0047
0.0203	0.0206	0.0435	-0.0064	-0.0018	-0.0032	0.0425
[illegible]	0.0090	-0.0203	-0.0130	-0.0025	-0.0264	0.0356
[illegible]	[illegible]	-0.0091	0.0076	-0.0192	0.0274	-0.0353

COEFFICIENT MATRIX A4

0.0394	0.0110	-0.0057	0.0022	-0.0320	0.0015	0.0090
0.0041	0.0040	0.0013	-0.0211	-0.0268	0.0283	0.0338
0.0335	-0.0048	-0.0508	0.0132	-0.0158	0.0160	-0.0182
0.0216	0.0014	-0.0014	0.0148	-0.0342	-0.0215	0.0090
[illegible]	-0.0081	-0.0130	-0.0332	-0.0403	-0.0324	0.0037
0.0169	-0.0347	0.0293	-0.0167	0.0030	-0.0012	-0.0298
-0.0332	-0.0075	-0.0807	0.0495	0.0140	-0.0383	-0.0080

COEFFICIENT MATRIX A5

-0.0102	-0.0198	0.0541	0.0081	-0.0216	0.0146	-0.0086
-0.0012	-0.0223	0.0189	0.0209	-0.0395	-0.0093	-0.0068
0.0302	0.0012	0.0351	-0.0275	-0.0175	0.0386	0.0074
-0.0093	-0.0020	0.0459	0.0180	-0.0090	0.0094	-0.0111
-0.0200	-0.0002	0.0282	0.0263	-0.0171	0.0131	0.0035
0.0223	0.0112	0.0356	-0.0451	-0.0540	0.0019	0.0564
-0.0058	-0.0026	0.0608	-0.0198	-0.0201	0.0009	0.0070

COEFFICIENT MATRIX A6

-0.0078	-0.0202	0.0131	-0.0088	0.0106	0.0134	-0.0255
0.0422	-0.0241	-0.0163	-0.0453	0.0242	0.0336	0.0126
-0.0139	-0.0126	-0.0146	0.0115	0.0010	-0.0112	-0.0044
-0.0041	-0.0253	0.0230	-0.0046	0.0116	-0.0016	-0.0112
-0.0090	-0.0093	0.0140	0.0381	-0.0171	-0.0098	-0.0230
-0.0108	0.0039	-0.0089	0.0209	0.0221	0.0183	-0.0330
0.0068	-0.0110	0.0152	0.0131	0.0051	0.0268	-0.0197

COEFFICIENT MATRIX A7

-0.0102	0.0080	0.0017	0.0015	0.0079	0.0046	-0.0257
0.0061	-0.0070	0.0233	-0.0032	-0.0163	0.0026	-0.0440
-0.0159	0.0047	-0.0115	0.0073	-0.0009	-0.0155	-0.0099
0.0001	-0.0076	0.0234	-0.0291	-0.0191	0.0392	-0.0025
-0.0159	-0.0001	0.0258	-0.0070	0.0092	0.0205	0.0219
-0.0099	-0.0085	0.0005	-0.0094	0.0016	-0.0398	0.0144
-0.0179	-0.0041	0.0082	-0.0250	-0.0023	0.0071	0.0029

COEFFICIENT MATRIX A8

-0.0385	-0.0406	0.0325	-0.0443	-0.0326	-0.0113	-0.0187
-0.0352	-0.0563	0.0052	-0.0354	-0.0022	-0.0284	0.0094
0.0233	0.0032	-0.0255	-0.0208	-0.0088	-0.0351	-0.0090
-0.0230	-0.0087	0.0009	-0.0382	-0.0332	0.0036	-0.0443
0.0123	-0.0088	-0.0022	-0.0015	-0.0134	-0.0240	-0.0092
-0.0240	0.0090	-0.0066	0.0121	0.0012	-0.0307	0.0107
0.0015	-0.0104	0.0316	-0.0524	-0.0154	0.0251	-0.0407

COEFFICIENT MATRIX A9

0.0324	0.0342	-0.0214	0.0381	-0.0010	-0.0090	0.0240
0.0149	0.0318	0.0003	0.0285	-0.0204	0.0126	0.0125
-0.0125	0.0038	0.0088	0.0194	0.0046	0.0366	0.0027
0.0226	0.0088	0.0297	0.0280	0.0118	-0.0046	0.0151
-0.0144	0.0276	-0.0103	0.0033	-0.0231	0.0097	-0.0032
0.0011	0.0291	-0.0030	0.0183	0.0166	-0.0314	-0.0127
-0.0106	0.0162	-0.0089	0.0411	0.0356	-0.0249	0.0061

APPENDIX D

PROGRAM LISTING AND FLOWCHART OF ANALYSIS PROCEDURES

```
C  THIS PROGRAM IS USED TO SELECT THE PROPER ORDER MVAR MODEL AND
C  DETERMINES THE COVARIANCE AND COEFFICIENT MATRICES FOR THAT MODEL
C  GIVEN II NP-DIMENSIONAL OBSERVATION VECTORS. THE MAXIMUM ORDER
C  MODEL CONSIDERED IS LGOLD-1. AFTER THE FINAL MVAR MODEL HAS
C  BEEN DETERMINED, THE PREDICTION ERROR MATRICES FOR VARIOUS-STEP
C  FORECASTS ARE COMPUTED BY SUBROUTINE ERRVAR.
      DIMENSION GAM(7,7,10),A(7,7,10),AB(7,7,10),B(7,7,10),
     1 BB(7,7,10),X(7,8768),XMN(7),S(7,7),SB(7,7),EE(7,7),DD(7,7),
     2 Q(7,7),S1(10),AA(7,7),ITOT(7,7)
      NP=7
C  NP IS THE NUMBER OF PREDICTOR VARIABLES.
      NC=
C  NC IS THE NUMBER OF VARIABLES TO BE PREDICTED, NC IS LESS THAN
C  EQUAL TO NP.
      LGOLD=10
C  LGOLD IS ONE MORE THAN THE MAXIMUM ORDER MVAR MODEL TO BE CONSIDERED
      LG=LGOLD
      II=8768
C  II IS THE NUMBER OF OBSERVATION VECTORS TO WHICH MVAR MODELS ARE
C  TO BE FITTED.
C*************************************************************************
C  BEFORE SUBROUTINE RHJONS IS CALLED FOR THE FIRST TIME THE
C  OBSERVATION VECTORS ARE PLACED IN ARRAY X DIMENSIONED NP BY II.
C  THE NC VARIABLES TO BE PREDICTED ARE DENOTED BY FIRST SUBSCRIPTS
C  1 THROUGH NC IN ARRAY X WHILE SUBSCRIPTS NC+1 THROUGH NP DENOTE
C  THE NP-NC VARIABLES TO BE USED TO AID IN THE PREDICTION. OF COURSE
C  NP MAY EQUAL NC.
C*************************************************************************
      CALL RHJONS(X,S,A,S1,II,NP,NC,LG,XMN,GAM,SB,EE,DD,AB,B,BB,Q,ITOT
C  AFTER THE FIRST CALL TO RHJONS, ARRAY S1 IS SCANNED TO FIND THE
C  THE MINIMUM VALUE OF THE AKAIKE FPE PARAMETER BY SUBROUTINE
C  FPEMIN.  THE ORDER MODEL FOR WHICH THE MINIMUM OCCURS IS LMIN-1.
      CALL FPEMIN(S1,LG,LMIN)
      DD(1,1)=99999.
      LG=LMIN
C  SUBROUTINE RHJONS IS CALLED AGAIN TO DETERMINE THE COVARIANCE AND
C  COEFFICIENT MATRICES OF THE MVAR MODEL WITH THE MINIMUM VALUE
C  OF THE AKAIKE FPE PARAMETER.  DD(1,1)=99999. PREVENTS THE
C  RECOMPUTATION OF THE LAG-SUM MATRICES GAM.
      CALL RHJONS(X,S,A,S1,II,NP,NC,LG,XMN,GAM,SB,EE,DD,AB,B,BB,Q,ITOT)
C  SUBROUTINE ERRVAR IS CALLED TO COMPUTE THE PREDICTION ERROR
C  MATRICES.  UPON ENTRY ARRAY S CONTAINS THE ONE-STEP PREDICTION
C  ERROR COVARIANCE MATRIX AND ARRAY A CONTAINS THE COEFFICIENT
C  MATRICES.  THE PREDICTION ERROR COVARIANCE MATRICES ARE
C  RETURNED IN ARRAY BB.
      CALL ERRVAR(A,B,S,BB,NP,LG)
      STOP
      END
```

```
      SUBROUTINE RHJONS(X,S,A,S1,II,NP,NC,LG,XMN,GAM,SB,EE,DD,AB,B,BB,Q
     1      ,ITOT)
C   SUBROUTINE RHJONS COMPUTES THE COEFFICIENT MATRICES AND DETERMINES TH
C   PROPER ORDER FOR A MULTIVARIATE AUTOREGRESSIVE (MVAR) MODEL. ON THE
C   FIRST CALL TO RHJONS, NP TIME SERIES EACH OF LENGTH II ARE INPUT INTC
C   ARRAY X. THE FIRST NC TIME SERIES ARE THOSE TO BE PREDICTED. LG-1 IS
C   THE MAXIMUM ORDER MVAR PROCESS TO BE FITTED TO THE DATA. THE MEAN OF
C   EACH TIME SERIES IS COMPUTED AND STORED IN XMN. THE AKAIKE FPE ARE
C   COMPUTED AND STORED IN S1. AFTER THE FIRST CALL, S1 IS SEARCHED FOR
C   ITS MINIMUM VALUE AND THE INDEX OF THAT VALUE. ON THE SECOND CALL TO
C   RHJONS, DD(1,1) IS SET TO 99999., AND LG IS SET TO THE INDEX OF THE
C   MINIMUM VALUE IN S1. AFTER THE SECOND CALL THE COEFFICIENT MATRICES
C   FOR THE LG-1 ORDER MVAR PROCESS ARE A(NP,NP,2), A(NP,NP,3), . . . ,
C   A(NP,NP,LG). THE ONE STEP PREDICTION COVARIANCE MATRIX IS S.
      DIMENSION GAM(NP,NP,LG),A(NP,NP,LG),AB(NP,NP,LG),B(NP,NP,LG)
      DIMENSION BB(NP,NP,LG)
      DIMENSION X(NP,II),XMN(NP),S(NP,NP),SB(NP,NP),EE(NP,NP),DD(NP,NP)
      DIMENSION Q(NC,NC),S1(LG),ITOT(NP,NP)
      DIMENSION WORK(1000)
      XII=II
C   WHEN DD(1,1) EQUALS 99999. THE LAG-SUM MATRICES GAM NEED NOT
C   BE COMPUTED.  MISSING OR BAD DATA IN ARRAY X IS DENOTED
C   BY THE VALUE OF -100.
      IF(DD(1,1).EQ.99999.) GO TO 123
      DO 1900 I=1,NP
      XMN(I)=0.
      ITOT(I,1)=0
      DO 1900 J=1,II
      IF(X(I,J).EQ.-100.) GO TO 1900
      ITOT(I,1)=ITOT(I,1)+1
      XMN(I)=XMN(I)+X(I,J)
 1900 CONTINUE
      DO 1901 I=1,NP
      XMN(I)=XMN(I)/ITOT(I,1)
      DO 1901 J=1,II
      IF(X(I,J).EQ.-100.) GO TO 1901
      X(I,J)=X(I,J)-XMN(I)
 1901 CONTINUE
      DO 100 I=1,NP
      DO 100 J=1,NP
      DO 100 K=1,LG
  100 GAM(I,J,K)=0.
      DO 61 L=1,LG
      DO 61 I=1,NP
      DO 61 J=1,NP
      ITOT(I,J)=0
      DO 62 K=L,II
      K1=K-L+1
      IF(X(I,K).EQ.-100..OR.X(J,K1).EQ.-100.) GO TO 62
      ITOT(I,J)=ITOT(I,J)+1
      GAM(I,J,L)=GAM(I,J,L)+X(I,K)*X(J,K1)
   62 CONTINUE
      GAM(I,J,L)=GAM(I,J,L)*(II-L+1)/ITOT(I,J)
   61 CONTINUE
  123 CONTINUE
      DO 17 I=1,NP
      DO 17 J=1,NP
      A(I,J,1)=0.
      B(I,J,1)=0.
```

```
      AB(I,J,1)=0.
      BB(I,J,1)=0.
   17 CONTINUE
      DO 7 I=1,NP
      B(I,I,1)=1.
      A(I,I,1)=1.
      BB(I,I,1)=1.
      AB(I,I,1)=1.
      DO 7 J=1,NP
      S(I,J)=GAM(I,J,1)
      SB(I,J)=S(I,J)
    7 CONTINUE
      IF( LG .LE. 1 ) GO TO 124
      DO 8 L=2,LG
      NL=L-1
      IF(NC.EQ.NP) GO TO 20
      DO 21 I=1,NC
      DO 21 J=1,NC
   21 Q(I,J)=S(I,J)
      CALL MATINV(Q,NC,DET)
      S1(NL)=DET
   20 CONTINUE
      CALL MATINV(S,NP,DET)
      IF(NC.NE.NP) GO TO 22
      S1(NL)=DET
   22 CONTINUE
      CALL MATINV(SB,NP,DET)
      DO 9 I=1,NP
      DO 9 J=1,NP
      DD(I,J)=0.
      EE(I,J)=0.
      DO 9 K=1,NL
      K1=L-K+1
      DO 9 I1=1,NP
      EE(I,J)=EE(I,J)-BB(I,I1,K)*GAM(J,I1,K1)
      DD(I,J)=DD(I,J)-B(I,I1,K)*GAM(I1,J,K1)
    9 CONTINUE
      DO 11 I=1,NP
      DO 11 J=1,NP
      A(I,J,L)=0.
      AB(I,J,L)=0.
      DO 11 K=1,NP
      A(I,J,L)=A(I,J,L)+DD(I,K)*SB(K,J)
   11 AB(I,J,L)=AB(I,J,L)+EE(I,K)*S(K,J)
      IF(L.EQ.2) GO TO 12
      DO 13 K=2,NL
      KN=L-K+1
      DO 13 I=1,NP
      DO 13 J=1,NP
      A(I,J,K)=B(I,J,K)
      AB(I,J,K)=BB(I,J,K)
      DO 13 K1=1,NP
      A(I,J,K)=A(I,J,K)+A(I,K1,L)*BB(K1,J,KN)
   13 AB(I,J,K)=AB(I,J,K)+AB(I,K1,L)*B(K1,J,KN)
   12 CONTINUE
      DO 14 I=1,NP
      DO 14 J=1,NP
      DO 14 K=1,L
      B(I,J,K)=A(I,J,K)
   14 BB(I,J,K)=AB(I,J,K)
```

```
      DO 15 I=1,NP
      DO 15 J=1,NP
      S(I,J)=GAM(I,J,1)
      SB(I,J)=GAM(I,J,1)
      DO 15 K=2,L
      DO 15 K1=1,NP
      S(I,J)=S(I,J)+A(I,K1,K)*GAM(J,K1,K)
   15 SB(I,J)=SB(I,J)+AB(I,K1,K)*GAM(K1,J,K)
    8 CONTINUE
 124  CONTINUE
      DO 778 I=1,NC
      DO 778 J=1,NC
  778 Q(I,J)=S(I,J)
      CALL MATINV(Q,NC,DET)
      S1(LG)=DET
      WRITE(6,1800) S1
      DO 200 I=1,LG
      F1=II+(I-1)*NP+1
      F2=II-(I-1)*NP-1
      F12=(F1/F2)**NC
  200 S1(I)=S1(I)*F12
      SF=S1(1)
      DO 201 I=1,LG
  201 S1(I)=S1(I)/SF
      WRITE(6,1800) S1
 1800 FORMAT(2X,'S1',10E12.4)
      DO 77 I=1,LG
      IF(S1(I).LE.0.) S1(I)=1.
   77 S1(I)=ALOG10(S1(I))
      FN=II-(LG-1)*NP-1
      DO 78 I=1,NP
      DO 78 J=1,NP
   78 S(I,J)=S(I,J)/FN
      RETURN
      END
```

```
      SUBROUTINE PPEMIN(S1,LG,LMIN)
C THIS SUBROUTINE SEARCHES THE VALUES OF THE AKAIKE FPE PARAMETER
C CONTAINED IN ARRAY S1.  THE MINIMUM IS FOUND AND THE ARRAY
C POSITION IS DENOTED BY LMIN.  THIS CORRESPONDS TO AN MVAR MODEL
C ORDER OF LMIN-1.
      DIMENSION S1(LG)
      SMIN=1.E50
      DO 1 I=1,LG
      IF(S1(I).GT.SMIN) GO TO 1
      LMIN=I
      SMIN=S1(I)
    1 CONTINUE
      PRINT (6,5) LMIN,S1(LMIN)
    5 FORMAT(2X,'LMIN,PPEMIN',I5,E13.5)
      [illegible]
    6 FORMAT(5X,5E13.5)
      RETURN
      END
C
C
C
      SUBROUTINE MATINV (A,M,DET)
C THIS SUBROUTINE COMPUTES THE INVERSE MATRIX OF M BY M MATRIX
C A AND RETURNS THE INVERSE IN A.  THE DETERMINANT OF A IS
C RETURNED IN DET.
      DIMENSION A(M,M)
      DET=1.0
      DO 1 J=1,M
      PVT=A(J,J)
      DET=DET*PVT
      A(J,J)=1.0
      DO 2 K=1,M
    2 A(J,K)=A(J,K)/PVT
      DO 1 K=1,M
      IF (K-J) 3,1,3
    3 T=A(K,J)
      A(K,J)=0.0
      DO 4 L=1,M
    4 A(K,L)=A(K,L)-(A(J,L)*T)
    1 CONTINUE
      RETURN
      END
```

```
THIS PROGRAM IS USED TO MAKE 3, 6, 9, AND 12 HOUR MVAR FORECASTS
AND THEN COMPUTE THE 80% CONFIDENCE INTERVALS TO BE PLACED ABOUT
THEM AND COMPARE THE FORECASTS WITH THE ACTUAL OBSERVATIONS VALID
AT THE FORECAST TIME.
      DIMENSION XMN(7),A(7,7,10),ARD(7,7),YDAT(7,13),DRD(7),
     1       ZDAT(7,4),XDAT(7,9),V(7,7),VV(7,7,10),B(7,7,10),
     2       FHI(7,4),FLO(7,4),XTOMN(7),XHRMN(7,8),XMOMN(7,12)
      DIMENSION IVARN(28),ISTAN(21)
      DATA ISTAN/4HHANN,4HOVER,4H    ,4HBREM,4HEN  ,4H    ,
     1  4HBOIZ,4HENBU,4HRG  ,4HBRAU,4HNSCH,4HWEIG,4HMAGD,
     2  4HEBUR,4HG   ,4HWERN,4HIGER,4HODE ,4HWEIS,4HSEN ,4H    /
      DATA IVARN /4H1ST ,4HCLD ,4HLAYE,4HR HT,4HCEIL,4HING ,
     1  4HHT  ,4H    ,4HTEMP,4HERAT,4HURE ,4H    ,4H    ,4H    ,
     2  4H    ,4H    ,4HVISI,4HBILI,4HTY  ,4H    ,4HU-WI,4HND  ,
     3  4H    ,4H    ,4HV-WI,4HND  ,4H    ,4H    /
KVAR IS THE VARIABLE NUMBER...1=HEIGHT OF FIRST CLOUD LAYER,
2=CEILING HEIGHT, 3=TEMPERATURE, 5=VISIBILITY, 6=U-WIND, AND
7=V-WIND.  NP IS THE NUMBER OF PREDICTOR VARIABLES. LG IS THE
ORDER OF THE MVAR MODEL PLUS ONE. THUS, FOR A 9TH ORDER MODEL
LG WOULD EQUAL 10.
      READ(5,201) KVAR,NP,LG
  201 FORMAT(10I8)
      LGM1=LG-1
      LGM2=LG-2
      LGP3=LG+3
THE MEAN VECTOR, ONE-STEP PREDICTION ERROR COVARIANCE MATRIX,
AND THE COEFFICIENT MATRICES FOR THE MVAR MODEL ARE READ IN
HERE.  THE SAMPLE MEAN VECTOR, WHICH IS DETERMINED AND REMOVED
BEFORE THE LAG-SUM MATRICES ARE COMPUTED, IS READ INTO ARRAY
XMN.  THE COVARIANCE MATRIX IS READ INTO ARRAY V AND THE
COEFFICIENT MATRICES ARE READ INTO ARRAY ARD AND THEN PLACED
IN ARRAY A.  A(I,J,1) WILL ALWAYS BE THE IDENTITY MATRIX WHILE
COEFFICIENT MATRICES A1,A2,A3,... WILL BE PLACED IN A(I,J,2),
A(I,J,3),A(I,J,4),...,RESPECTIVELY.
      READ(5,200) XMN
  200 FORMAT(7F11.5)
      READ(5,200) ((V(I,J),J=1,7),I=1,7)
      DO 5 L=1,LG
      READ(5,200) ((ARD(I,J),J=1,7),I=1,7)
      DO 5 I=1,NP
      DO 5 J=1,NP
    5 A(I,J,L)=ARD(I,J)
IF THE VARIABLE IS TEMPERATURE, THE GRAND MEANS, HOURLY MEANS
AND MONTHLY MEANS WHICH WERE REMOVED BEFORE THE MVAR MODEL
WAS DETERMINED, MUST BE READ IN HERE SO THAT THEY MAY BE
ADDED BACK TO THE FORECAST VALUES.
      IF(KVAR.NE.3) GO TO 110
      READ(5,101) XTOMN
      READ(5,101) ((XHRMN(I,J),I=1,7),J=1,8)
      READ(5,101) ((XMOMN(I,J),I=1,7),J=1,12)
  101 FORMAT(7F8.3)
  110 CONTINUE
      CALL ERRVAR(A,B,V,VV,NP,LG)
THE OBSERVATIONS TO BE USED TO MAKE AND VERIFY THE FORECASTS
ARE READ IN HERE. IT IS ASSUMED THAT THE CONTRIBUTION OF
THE HOURLY AND MONTHLY MEANS HAVE BEEN REMOVED BEFORE THE
TEMPERATURE DATA HAS BEEN READ IN AND THAT TRANSFORMED
VISIBILITY AND CLOUD HEIGHT VARIABLES ARE TO BE READ IN.
ARRAY YDAT IS DIMENSIONED NP BY LG+3.  THE OBSERVATION TO
```

```
C  BE OBTAINED WITH THE 12-HOUR FORECAST IS CONTAINED IN ELEMENT
C  YDAT(I,1), THE OBSERVATION VALID AT THE ZERO FORECAST TIME
C  IS CONTAINED IN YDAT(I,5), AND THE OBSERVATION FARTHEST IN
C  THE PAST IS CONTAINED IN YDAT(I,LG+3).
      READ(5,200) ((YDAT(I,J),I=1,NF),J=1,LGP3)
      DO 10 I=1,NF
      DO 10 J=1,LGM1
   10 XDAT(I,J)=YDAT(I,J+4)-XMN(I)
      DO 20 IFCST=1,4
      IF(IFCST.EQ.1) GO TO 21
      DO 22 I=1,NF
      DO 23 J=1,LGM2
   23 XDAT(I,LG-J)=XDAT(I,LGM1-J)
      XDAT(I,1)=FDAT(I,IFCST-1)
   22 CONTINUE
   21 CONTINUE
      DO 25 I=1,NF
      FDAT(I,IFCST)=0.
      DO 25 L=1,LGM1
      DO 25 J=1,NF
   25 FDAT(I,IFCST)=FDAT(I,IFCST)-A(I,J,L+1)*XDAT(J,L)
   20 CONTINUE
      IF(KVAR.NE.3) GO TO 210
C  THE HOUR AND MONTH OF THE FORECAST ZERO TIME ARE READ IN
C  HERE ONLY FOR TEMPERATURE SO THAT THE MONTHLY AND HOURLY
C  MEANS CAN BE ADDED BACK IN.  IHRF=1 FOR 00Z, IHRF=2 FOR 03Z,
C  ...,IHRF=8 FOR 21Z.  IMOF=1 FOR JANUARY AND IMOF=12 FOR
C  DECEMBER.
      READ(5,201) IHRF,IMOF
      DO 211 I=1,NF
      DO 211 J=1,4
      IHR=IHRF+J
      IF(IHR.GT.8) IHR=IHR-8
      IMO=IMOF
      FDAT(I,J)=FDAT(I,J)+XHRMN(I,IHR)+XMOMN(I,IMO)-XTOMN(I)
      YDAT(I,5-J)=YDAT(I,5-J)+XHRMN(I,IHR)+XMOMN(I,IMO)-XTOMN(I)
  211 CONTINUE
  210 CONTINUE
      DO 30 I=1,NF
      DO 30 J=1,4
      FDAT(I,J)=FDAT(I,J)+XMN(I)
      SD=SQRT(VV(I,I,J))
      FHI(I,J)=FDAT(I,J)+1.28*SD
      FLO(I,J)=FDAT(I,J)-1.28*SD
      ICHK=KVAR
      IF(ICHK.GT.2.AND.ICHK.NE.5) GO TO 30
      XMULT=1000.
      IF(ICHK.EQ.5) XMULT=2000.
      IF(FDAT(I,J).LE.0.) FDAT(I,J)=1.E-13
      IF(FHI(I,J).LE.0.) FHI(I,J)=1.E-13
      IF(FLO(I,J).LE.0.) FLO(I,J)=1.E-13
      FDAT(I,J)=-XMULT*ALOG(FDAT(I,J))
      XLO=FLO(I,J)
      XHI=FHI(I,J)
      FHI(I,J)=-XMULT*ALOG(XLO)
      FLO(I,J)=-XMULT*ALOG(XHI)
      IF(FLO(I,J).LT.0.) FLO(I,J)=0.
      YDAT(I,5-J)=-XMULT*ALOG(YDAT(I,5-J))
   30 CONTINUE
      KV1=(KVAR-1)*4+1
```

```
      KV2=KV1+3
      WRITE(6,900) (IVARN(KV),KV=KV1,KV2)
  900 FORMAT(/2X,4A4/)
      DO 40 I=1,NP
      IST1=(I-1)*3+1
      IST2=IST1+2
      WRITE(6,901) (ISTAN(IST),IST=IST1,IST2)
  901 FORMAT(/2X,3A4/)
      WRITE(6,41) I,(FDAT(I,J),J=1,4),(YDAT(I,5-J),J=1,4)
   41 FORMAT(2X,'I=',I5,' FCST',4E13.5,' ACTUAL',4E13.5)
      WRITE(6,42) (FLC(I,J),J=1,4),(FHI(I,J),J=1,4)
   42 FORMAT(9X,' .80 LC',4E13.5,' .80 HI',4E13.5)
   40 CONTINUE
      STOP
      END
```

```
      SUBROUTINE ERRVAR(A,B,V,VV,NP,LG)
      DIMENSION V(NP,NP),A(NP,NP,LG),B(NP,NP,LG),VV(NP,NP,LG)
      DO 1 I=1,NP
      DO 1 J=1,NP
    1 VV(I,J,1)=V(I,J)
      LGM1=LG-1
      DO 6 L=1,LGM1
      DO 6 I=1,NP
      DO 6 J=1,NP
      DO 6 LK=1,L
      IF(LK.GT.1) GO TO 7
      B(I,J,L)=-A(I,J,L+1)
      GO TO 6
    7 CONTINUE
      DO 8 KK=1,NP
    8 B(I,J,L)=B(I,J,L)-B(I,KK,LK-1)*A(KK,J,LK)
    6 CONTINUE
      DO 10 L=2,LG
      DO 10 I=1,NP
      DO 10 J=1,NP
      VV(I,J,L)=VV(I,J,L-1)
      DO 10 KK=1,NP
      DO 10 LL=1,NP
   10 VV(I,J,L)=VV(I,J,L)+B(I,KK,L-1)*VV(KK,LL,1)*B(J,LL,L-1)
      RETURN
      END
```

FLOWCHART OF ANALYSIS PROCEDURE

Initialization

Before any subroutine calls: II is the number of NP-dimensional observation vectors an MVAR model is to be found for, the maximum order model to be tried is LG-1, the array X dimensioned NP by II contains the observation vectors.

1st Call of Subroutine RHJONS

MVAR models of order zero to order LG are fitted to the II NP-dimensional observation vectors. The values of the Akaike FPE parameter are stored in array S1.

Call Subroutine FPEMIN

Array S1 is searched for the minimum value of the FPE parameter. Array element LMIN denotes the minimum and LMIN-1 is the order of the MVAR model.

2nd Call of Subroutine RHJONS

An MVAR model of order LMIN-1 is fitted to the II NP-dimensional observation vectors. The one-step prediction error covariance matrix is contained in array S and the coefficient matrices in array A.

Call Subroutine ERRVAR

Prediction error covariance matrices for various step forecasts are computed and contained in array B3.

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